Journal

WATER POLLUTION CONTROL FEDERATION

FORMERLY SEWAGE AND INDUSTRIAL WASTES

Special Features

Curved Sewers—Ludwig

Water Quality—ORSANCO

Underground Disposal—Morris

Syndets and Aeration—Lynch and Sawyer

Spray Irrigation—Hickerson and McMahon

Operator's Corner

Paints, Sludge Drying, Electrical Maintenance

JANUARY 1960

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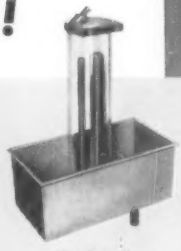

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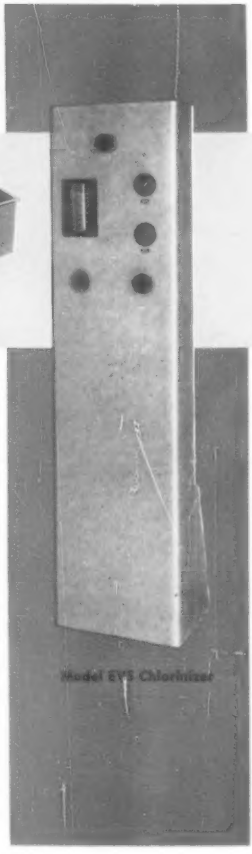

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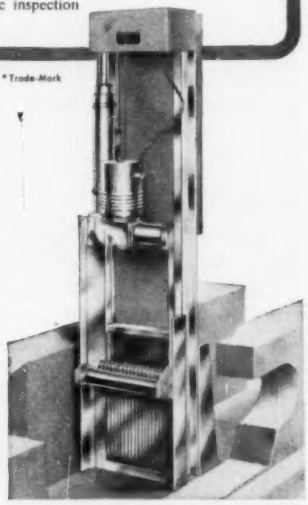

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JOURNAL of the WATER POLLUTION CONTROL FEDERATION

Volume 32 | January 1960 | Number 1

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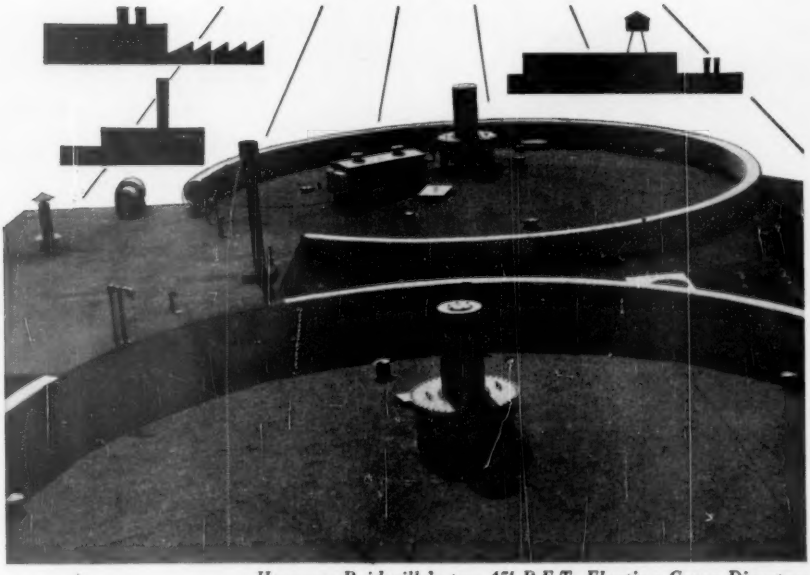
Mailing Permit: Second class postage paid at Lancaster, Pa., and at additional mailing offices.



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EDITORIAL AND EXECUTIVE OFFICES: 4435 Wisconsin Ave., N.W., Washington 16, D. C. Send all manuscripts, advertising copy, subscriptions, address changes, etc., to this address.

PUBLICATION OFFICE: Prince and Lemon Sts., Lancaster, Pa.

SUBSCRIPTION RATES: Members of local associations affiliated with the Federation, $8.00 per year. Nonmembers, U. S. and Canada: $10.00; other countries, $11.50. (Foreign subscriptions must be accompanied by International Money Order.) Single copies: United States, $1.25 each; Foreign, $1.50 each.

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REFERENCE SERVICE: Journal of the Water Pollution Control Federation is indexed regularly by *Industrial Arts Index* and *Engineering Index*. Microfilm copies of this Journal may be procured from University Microfilms, Ann Arbor, Mich. This service is limited to regular subscribers only.

Library of Congress Catalog Card Number: 42-19992.

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Air view of new secondary treatment facilities at Wichita, Kansas. Two 205 ft. dia. final basins, with Eimco-Process Clarifier mechanisms, have been completed and the third unit (lower left) is under construction. Consulting Engineers—Black & Veatch, Kansas City, Missouri.

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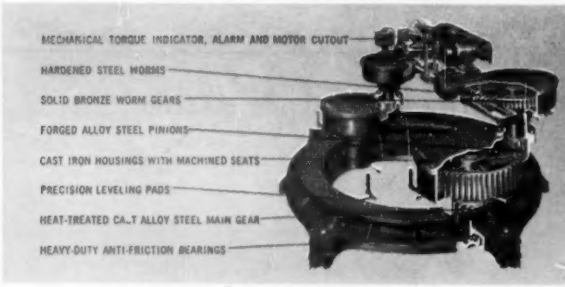
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Utah Sewage and Industrial Wastes Assn.	Union Building Univ. of Utah Salt Lake City, Utah	Feb. 1
Texas Water and Sewage Works Assn.	Memorial Student Center Texas A & M College Station, Tex.	Feb. 28–Mar. 4
Mississippi Sewage and Industrial Wastes Assn.	Robert E. Lee Hotel Jackson, Miss.	Mar. 4
Arkansas Water and Sewage Conf.	Marion Hotel Little Rock, Ark.	Mar. 13–16
Louisiana Conference on Water Supply and Sewerage	La. State Univ. Baton Rouge, La.	March 16–18
West Virginia Sewage and Industrial Wastes Assn.	Hotel Pritchard Huntington, W. Va.	Mar. 23–24
New Jersey Sewage and Industrial Wastes Assn.	Traymore Hotel Atlantic City, N. J.	Mar. 30–Apr. 1
Kansas Sewage and Industrial Wastes Assn.	Broadview Hotel Emporia, Kan.	Apr. 22–24
California Sewage and Industrial Wastes Assn.	Hotel Claremont Berkeley, Calif.	Apr. 27–30
Arizona Sewage and Water Works Assn.	Pioneer Hotel Tucson, Ariz.	Apr. 28–30
Montana Sewage and Industrial Wastes Assn.	Northern Hotel Billings, Mont.	Apr. 28–30

THIRTY-THIRD ANNUAL MEETING

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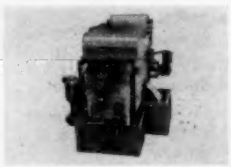

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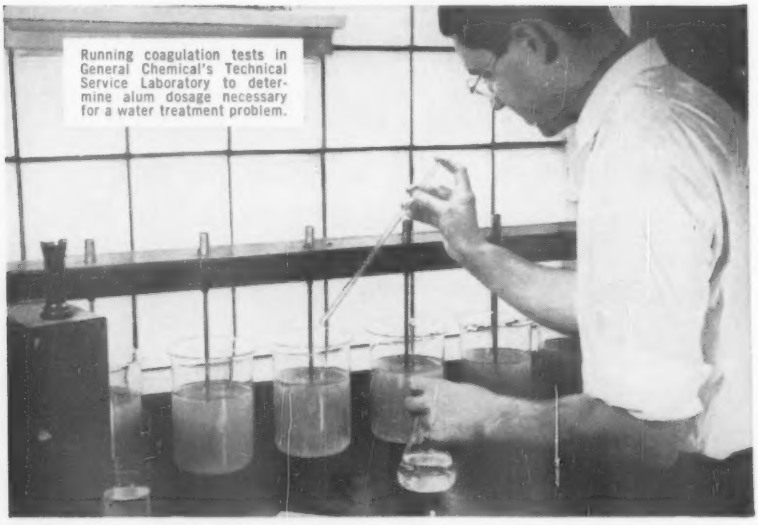
INFILCO can help you and your engineer evaluate any industrial waste disposal problem.

Write today for Bulletin 80-A for a complete listing of INFILCO equipment.



Running coagulation tests in General Chemical's Technical Service Laboratory to determine alum dosage necessary for a water treatment problem.

Another difference in GENERAL CHEMICAL ALUM is TECHNICAL SERVICE

As the country's primary producer of aluminum sulfate, General Chemical constantly helps customers solve technical problems involving the use of alum. Results? Improved efficiency and reduced operating costs for them. Here are some of the services our Technical Service Department offers:

- Supplying basic information helpful in planning design and installation of storing, pumping, metering and feeding facilities.
- Suggesting improvements to eliminate existing storing and handling problems.
- Providing chemists and operators with physical and chemical data necessary for the most effective use of alum.
- Assisting in laboratory tests and plant trials.
- Running check analyses in our own laboratories.

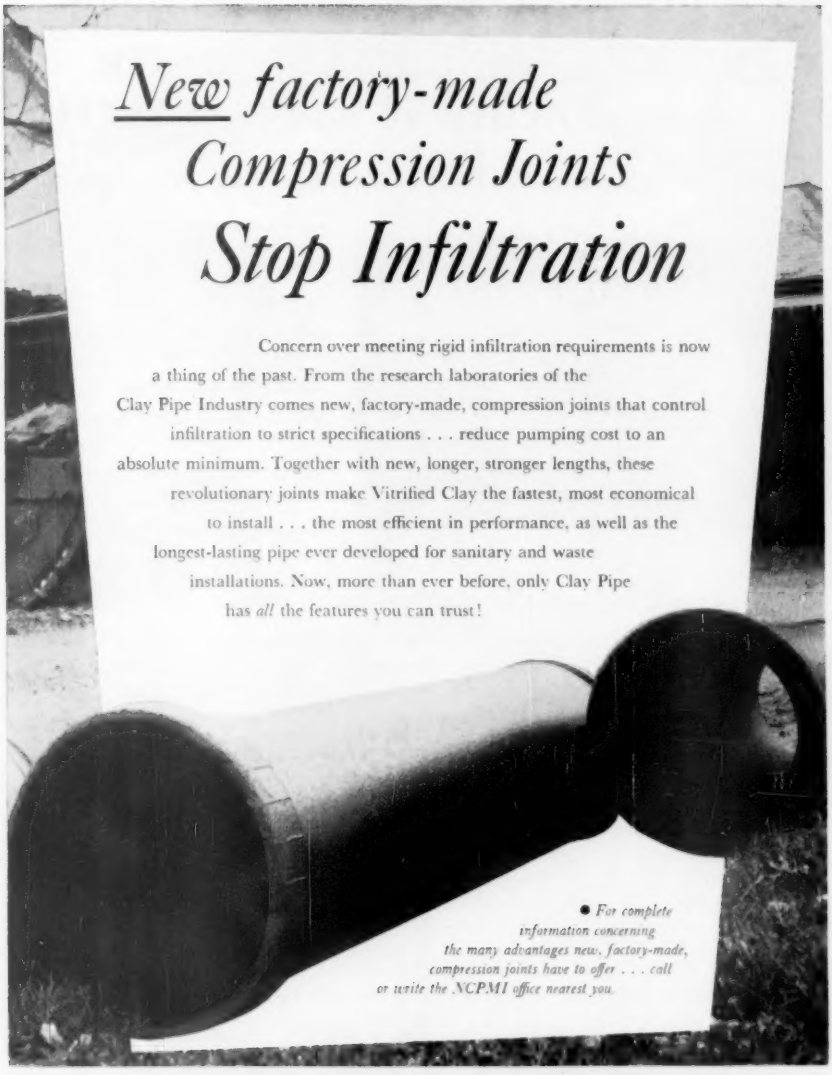
In water and sewage plants, our specialists provide valuable help and guidance on storage, handling and feeding problems, as well as the important conversion from dry to liquid alum. They can help plant operators establish the best alum dosage. They recommend coagulation aids to improve flocculation in difficult water or waste treatment conditions.

This kind of Technical Service is one of the reasons why General Chemical is a good company to do business with for *your* plant's aluminum sulfate requirements. We will welcome the opportunity to serve you.

Basic to America's Progress

Allied Chemical

GENERAL CHEMICAL DIVISION
40 Rector Street, New York 6, N. Y.


New factory-made
Compression Joints
Stop Infiltration
Concern over meeting rigid infiltration requirements is now a thing of the past. From the research laboratories of the Clay Pipe Industry comes new, factory-made, compression joints that control infiltration to strict specifications . . . reduce pumping cost to an absolute minimum. Together with new, longer, stronger lengths, these revolutionary joints make Vitrified Clay the fastest, most economical to install . . . the most efficient in performance, as well as the longest-lasting pipe ever developed for sanitary and waste installations. Now, more than ever before, only Clay Pipe has all the features you can trust!
● For complete information concerning the many advantages new, factory-made, compression joints have to offer . . . call or write the NCPMI office nearest you.

Vitrified **CLAY PIPE** Never Wears Out

NATIONAL CLAY PIPE MANUFACTURERS, INC.

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AMERICAN "*AIRCOMB*" DIFFUSER

WITH SELF-CLEANING NON-CLOG TEETH

Gives All the Aeration You Want . . . *just where and when you want it*

Teeth on *both sides* of the "Aircomb" provide simple, multiple, variable-flow orifices for controlled aeration.

No "*blurps*" at low air flows.

Unique *peaked-dome* design prevents accumulation of solids.

Velocities are self-cleansing.

Variable diffusion capacity as high as 5:1 if necessary.

Nothing to break or need replacement or change.

Fully proved in the field.

NOTHING CLINGS, FLINGS, OR SWINGS

—A TRUE TRIUMPH IN SIMPLICITY, ECONOMY, DURABILITY, AND EFFICIENCY

The AMERICAN "*Aircomb*" has very useful application in pre-aeration, channel diffusion, and activated sludge installations. It is especially preferred where relatively high tank content agitation is required and where other types of diffusers present operating difficulties due to clogging.

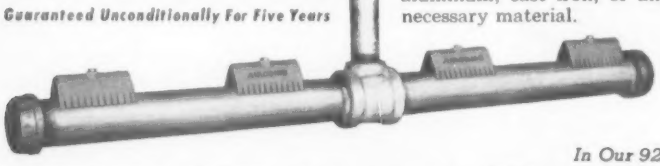
The "*Aircomb*" handles a very wide range of gas flow per diffuser unit. Orifices automatically adjust to the gas flow (the gas-liquid interface lowers as the rate increases). Bubble size also is smallest at the lowest flow. Velocities are self-cleansing.

The "*Aircomb*" is also the ideal diffuser for recarbonation, since carbon dioxide will go into solution readily. No maintenance is required.

Guaranteed Unconditionally For Five Years

It can be applied in a wide variety of mechanical arrangements, such as shown on header pipe illustrated below. More than one header with aircombs can be used parallel to each other as needed. Peaked-dome of the "*Aircomb*" prevents the accumulation of solids when used in settling tanks.

The "*Aircomb*" is cast in bronze, aluminum, cast iron, or any other necessary material.



In Our 92nd Year

Comprehensive Line of Field-Proved *PROCESSES AND EQUIPMENT*

The complete "American" line includes sewage, industrial waste, and water purification equipment; tank and pipeline mixers; deep well turbines; water transfer, clear liquid and waste water pumps. Consult "American" engineers or write for technical data.

AMERICAN WELL WORKS

110 N. BROADWAY — **AURORA, ILLINOIS**

Research, Engineering and Manufacturing — Waste and Water Treating, Mixing, and Pumping Equipment

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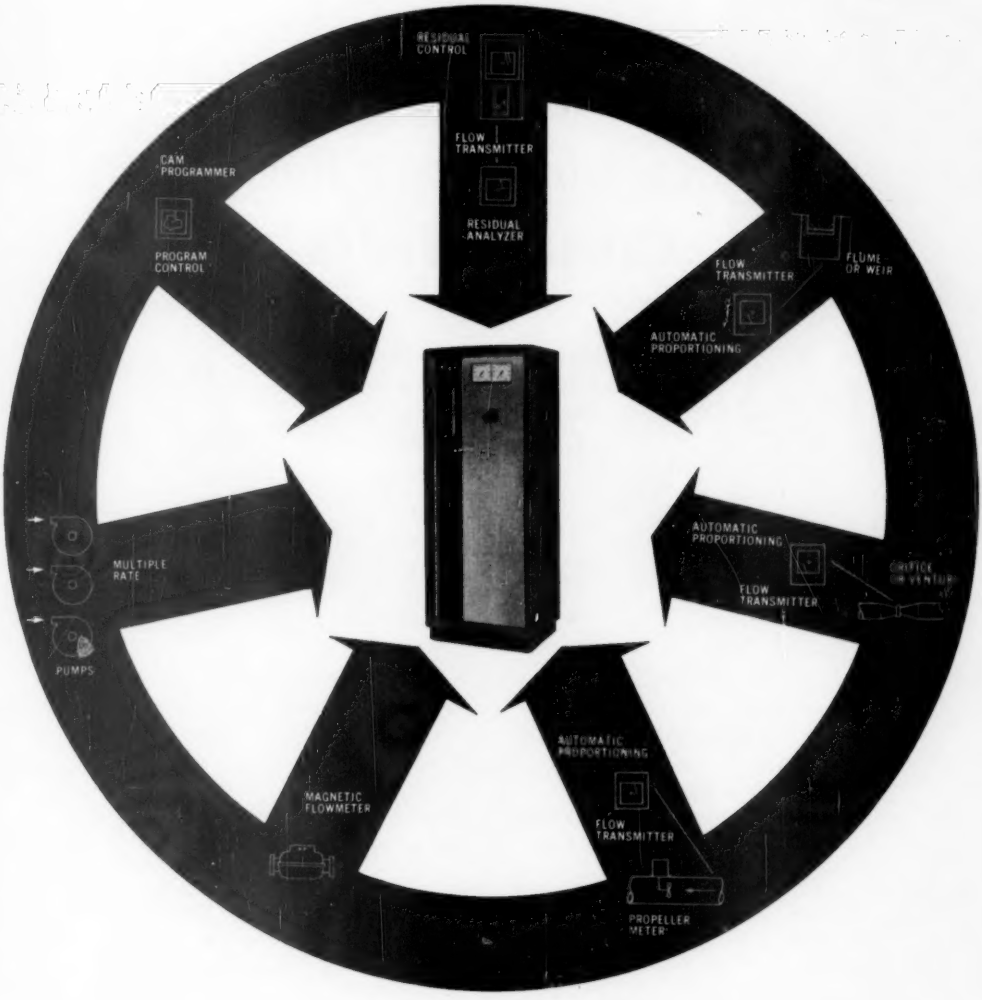
SALES OFFICES: CHICAGO, NEW YORK, AND OTHER PRINCIPAL CITIES



ELECTRICALLY CONTROLLED CHLORINATION SYSTEMS

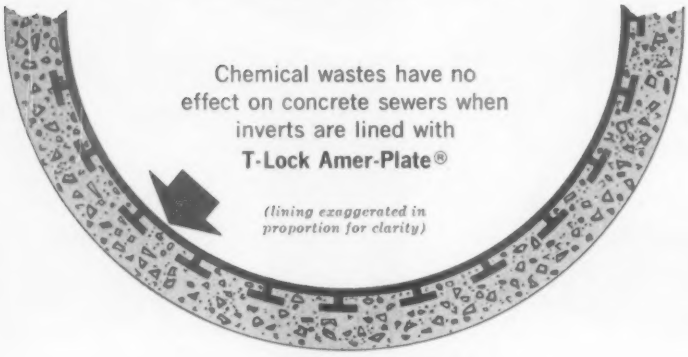
The commands are electric. The operation is automatic. Engineered by F & P . . . chlorination goes modern.

Regulate chlorine feed rate *precisely, automatically* with electrical signals from program controllers, multiple and step rate controllers, automatic proportioning controllers, remote controllers, magnetic flowmeters, and residual analyzers. Don't invest in *any* chlorination system until you check out **F & P Electrically Controlled Chlorination Systems.** Fischer & Porter Company, 1110 Fischer Road, Hatboro, Pennsylvania.

FP FISCHER & PORTER COMPANY *INSTRUMENTATION AND CHLORINATION*

These MANUFACTURING AFFILIATES carry Fischer & Porter engineering designs to the far corners of the earth: FISCHER & PORTER LTD., WORKINGTON, CUMBERLAND, ENGLAND • FISCHER & PORTER G.m.b.H., GROSS-ELLERSHAUSEN, BEI GOTTINGEN, GERMANY • FISCHER & PORTER N.V., KOMEETWEG 11, THE HAGUE, NETHERLANDS • FISCHER & PORTER Pty. LTD., 184 HANNA ST., SOUTH MELBOURNE, VICTORIA, AUSTRALIA.

How to Protect Concrete Sewers from Chemical Wastes



T-Lock Amer-Plate is a high polymer PVC sheet, easily cast into pipes, tunnels and structures to form a partial or complete 360° protective lining. Used in inverts, it permanently protects concrete from corrosive chemical effluents. In arch areas, it positively stops oxidized H_2S corrosion. T-Lock is also highly abrasion resistant; impartial tests show that it abrades at only 1/70th the rate of concrete.

The fact that T-Lock ends erosion and corrosion problems in industrial and municipal sewer systems is attested to by more than five million square feet now in use. Write for complete data on this maintenance-saving lining before designing your next sewer.

Applicators strategically located throughout U. S. and Canada

Amercoat® CORPORATION

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360 Carnegie Ave. Kenilworth, N.J.
2404 Dennis St. Jacksonville, Fla.
6530 Supply Row Houston, Texas

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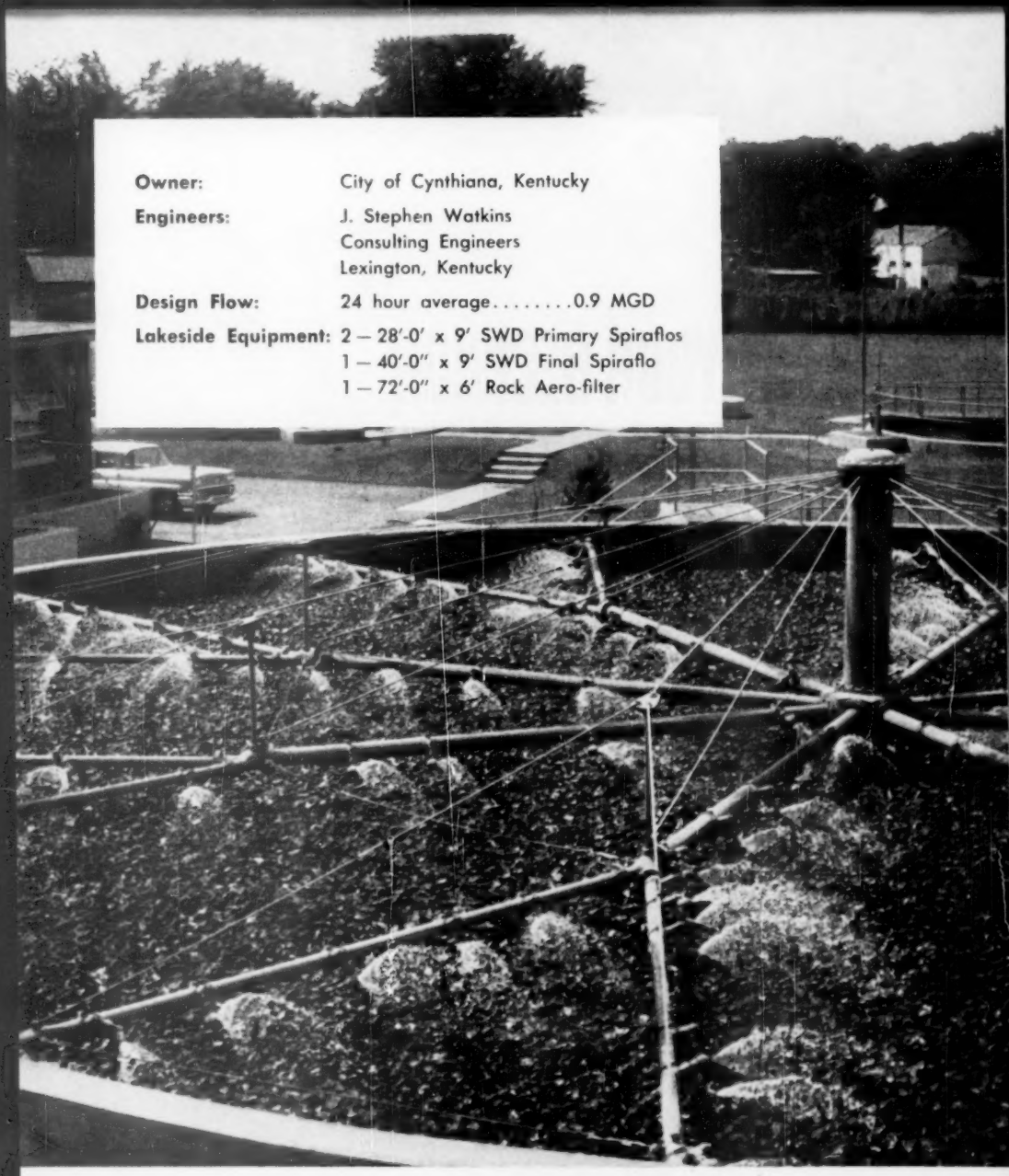


Owner:	City of Cynthiana, Kentucky
Engineers:	J. Stephen Watkins Consulting Engineers Lexington, Kentucky
Design Flow:	24 hour average.....0.9 MGD
Lakeside Equipment:	2 — 28′-0′ x 9′ SWD Primary Spiraflos 1 — 40′-0″ x 9′ SWD Final Spiraflo 1 — 72′-0″ x 6′ Rock Aero-filter

AERO-FILTERS: The high rate filter with raindrop-like application. Proven results based on the biologically accepted facts that proper feeding of a trickling filter will result in a consistently higher BOD removal per cubic yard of filter media. Added advantages include . . . smaller diameter filter beds, less filter fly nuisance, higher hydraulic loadings, and lower recirculation ratios. Over 200 Aero-filters in operation. *Write for Bulletin #116.*

LAKESIDE

ENGINEERING CORPORATION

222 West Adams St., Chicago 6, Illinois

IF YOUR DECISION MUST STAND UP FOR 100 YEARS

If your decision today will in some way determine your town's water supply system for the next century, consider the case for cast iron pipe:

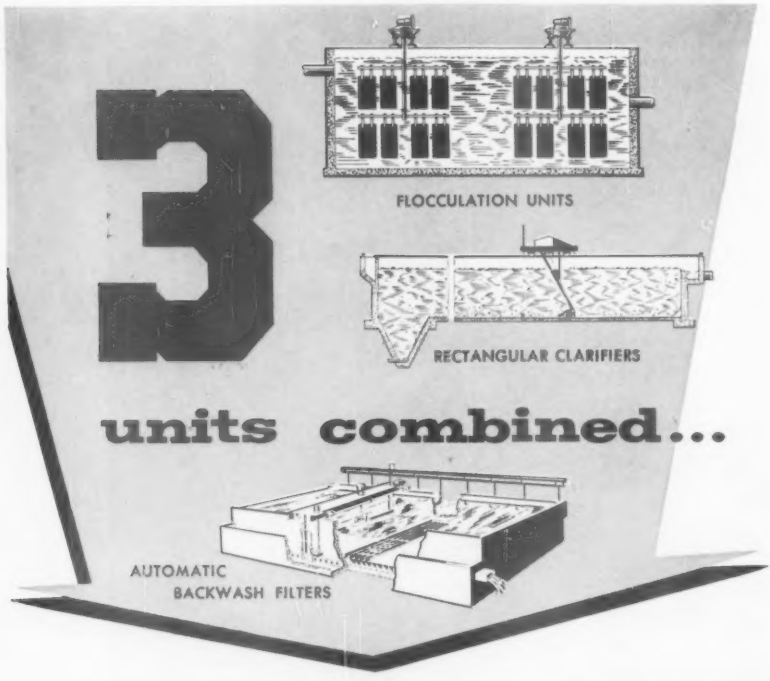
- Cast iron pipe is built to *last*—96 American cities will testify to that. They've had cast iron pipe installations in constant use for over a century! And in Versailles, France, they're still using cast iron pipe water mains that were laid in 1664! Solid proof that once cast iron pipe is in the ground, it stays there!
- Cast iron pipe rarely requires repair. Its rugged construction, corrosion-resistant qualities and bottle-tight, rubber-ring joints will withstand the most severe pressures. Once an investment is made in cast iron pipe, it is usually your first and last cost because of the absence of maintenance or repairs.

Don't be fooled by initial pipe costs. You can't save money on "low-cost" pipe if you have to repair and replace it frequently. Insist on the pipe that will actually save you money over a period of years—cast iron pipe!

THE MARK OF THE 100-YEAR PIPE

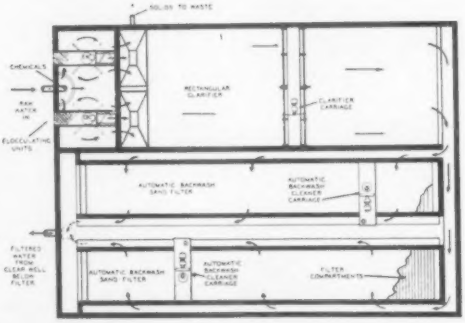
CAST IRON PIPE

Cast Iron Pipe Research Association, Thos. F. Wolfe, Managing Director, 3440 Prudential Plaza, Chicago 1, Illinois



. . . FOR COMPLETE WATER TREATMENT

For industrial and municipal water supplies, the Hardinge equipped water treatment plant is available in unit sizes of from 1 M.G.D. to 5 M.G.D. Flocculation, clarification, and filtration equipment—combined in modular units and sized to your requirements for a continuous supply of high-quality water.



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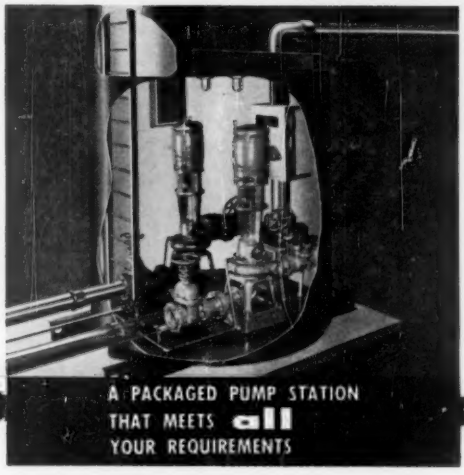
NOW . . .

FROM TEX-VIT



- **ADVANCED DESIGN FOR GREATER EFFICIENCY**
  Compare motor and pump assembly of this duplex sewage pump station with any other and see the TEX-VIT superiority. Individual shaft for each pump and each motor. Four bearings per assembly instead of the customary two. Heavy steel shell, completely protected from corrosion.
- **DIRECT PRESSURE CONTROLS FOR EXTRA RELIABILITY**
  Exclusive TEX-VIT controls are actuated by pressure variations within the wet well. No compressor to maintain; no floats or other moving parts in the wet well.
- **IMPROVED AIR CIRCULATION AND CONDITIONING**
  Extra large blower provides complete change of air every 60 seconds. Air inlet and outlet are at opposite sides of station to prevent short circuiting of air. Refrigeration-type dehumidifier.
- **SUPERIOR COMPONENTS FOR EXTRA DEPENDABILITY**
  Pumps, motors, controls, and other components bear the brand names you would expect to find in a *Who's Who of American Industry*. You know you are getting the best when you specify TEX-VIT.
- **INSTALLATION TESTED AND PROVED**
  TEX-VIT packaged pump stations are setting new standards. Names of muncipal and industrial users furnished on request.

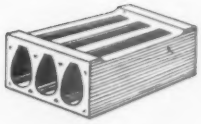
Let TEX-VIT help you with your sewage lift problems. TEX-VIT also makes pneumatic ejectors and packaged ejector stations.

Write for bulletin No. PS-60

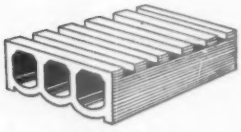
TEX-VIT
SUPPLY COMPANY
MANUFACTURING DIVISION
Dept. S-1, Box 117, Mineral Wells, Texas

30 YEARS FROM NOW...

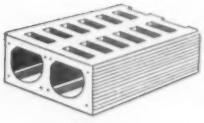
How Well Will Your Treatment Plant Still be Serving?



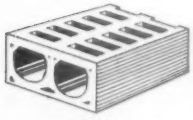
NATCO
Natco Corporation
Pittsburgh 22, Pa.



TRANSLOT
Cannelton Sewer Pipe Co.
Cannelton, Ind.



ARMCRE
Ayer-McCarel Clay Co., Inc.
Brazil, Ind.



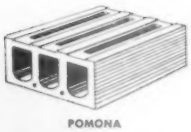
BOSCO
Bowerston Shale Co.
Bowerston, Ohio

Unpolluted water in ample supply is an immense industrial and recreational asset to any community. To end stream pollution, more and more trickling filters are being built. From 1945 to 1957 alone 926 of them were constructed, with the pace accelerating since. On the basis of past performance, many trickling filters will still be operating as well 30 years from now as they did when first installed. And no other type is easier to add to if growth exceeds your original estimates.

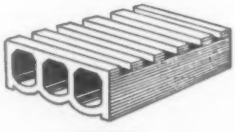
The most vital part of these trickling filters is the underdrain system. Failures here spell real trouble later. But when the floor is of TFFI Specification vitrified clay blocks this is guarded against. For it is inherent in clay to resist successfully the ravages of acids, alkalis and bacteriological action. TFFI clay underdrain blocks are made in modern plants under rigid controls of quality that no substitute material can even approach. (Only with them can you get a 50-Year Guarantee.)

Any member of the Institute listed on this page will be glad to send you a copy of the new approved specifications A.S.T.M. C 159–59T for use in designing trickling filters.

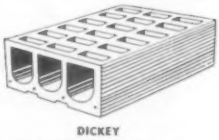
TRICKLING FILTER FLOOR INSTITUTE



POMONA
Pomona Terra-Cotta Co.
Pomona, No. Car.

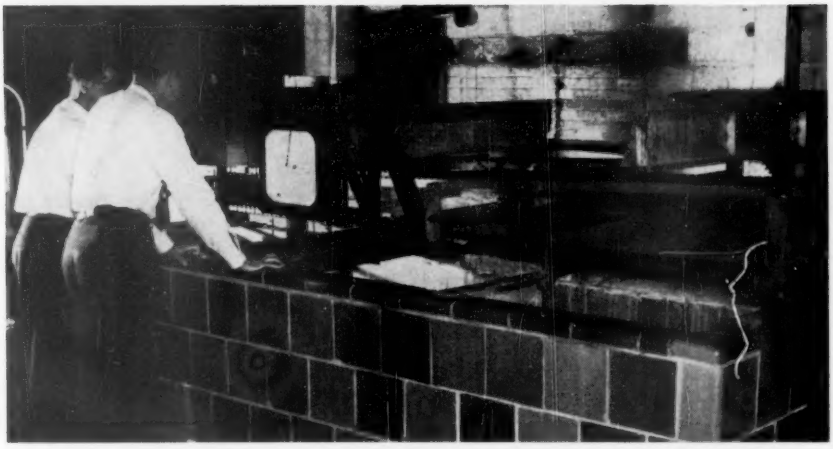


TRANSLOT
Texas Vitrified Pipe Co.
Mineral Wells, Texas



DICKEY
W. S. Dickey Clay Mfg. Co.
Kansas City 6, Mo.

FLUIDICS* AT WORK



Checking clarified effluent of the Permutit Colloidair Separator at the Homasote Company

How to side-step a public health hazard . . . and step into big new savings

Maybe you have a problem similar to the one that confronted the Homasote Company, Trenton, N. J.

They make high-density wood fiber insulation board. The process *could* create a waste disposal problem and impair the company's good community relations.

The answer found by Homasote turned out to be more than just a waste treatment system. It is also a valuable way to save money, through reclaimed product and water.

The Permutit Colloidair Separator is behind this accomplishment.

Saves product. White water feeds into the Colloidair, where a "bubbling-out" process raises the fibers to the surface. These fibers are scraped off and reclaimed.

Saves water. No water is wasted in this closed-circuit operation. Colloidair clarifies it for Homasote's re-use in pump glands, stuffing box seals, and for general cleanup.

Saves heat. The reclaimed water holds most of its heat during the clarifying process. This saves the expense of reheating for re-use.

Easy to use. Colloidair works almost by itself. The operator does little more than periodically charge chemical tanks.

Homasote is getting these benefits today . . . when would YOU like to start?

We will be glad to run lab and/or pilot plant tests to show just what the Permutit Colloidair Separator can do with your white waters and/or waste waters.

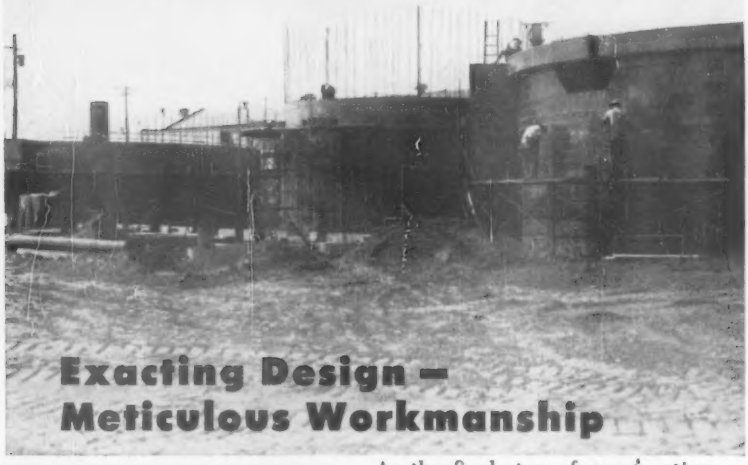
Save your public relations . . . and your money. Get more information on Colloidair by writing our Permutit Division, Dept. S1-10, 50 West 44th Street, New York 36, New York.

*FLUIDICS is a new Pfaudler Permutit program that provides a modern, imaginative approach for handling and processing liquids and gases more profitably.

PFAUDLER PERMUTIT INC.

Specialists in FLUIDICS . . . the science of fluid processes

Attractive, Corrosion-Resistant Glazed-Tile
Effluent and Water Treatment Tanks



Exacting Design —
Meticulous Workmanship

As the final step of construction, Stebbins workmen carefully wash down the exterior of the tanks with acid.

In this view of tank floors under construction, note the clean, smooth joints – the mark of good workmanship. Note the variety of tile shapes. Horizontal and vertical steel reinforcing is shown in the walls which will be solidly filled with concrete as work progresses.

Complete Service —
Design, Installation, Maintenance

WRITE FOR BULLETIN AET-59

SEMCO

STEBBINS Engineering and Manufacturing Company

WATERTOWN, N. Y. • PENSACOLA, FLORIDA

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Specialists in Design, Installation and Servicing of Linings and Tile Tanks

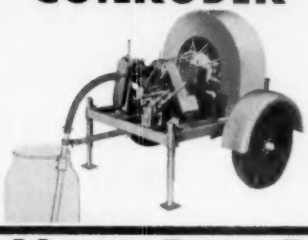
ONE SOURCE for ALL SEWER CLEANING EQUIPMENT

"Flexible"

SEWERODER

TRUCK-LODER

COILRODER



BUCKET MACHINE

MONORODER

"Flexible" Develops, Manufactures and Sells—

. . . the equipment with the *most* exclusive features for cleaning your sewers *faster*, safer and more economically.

POWER DRIVE

FLEXIBLE INC.

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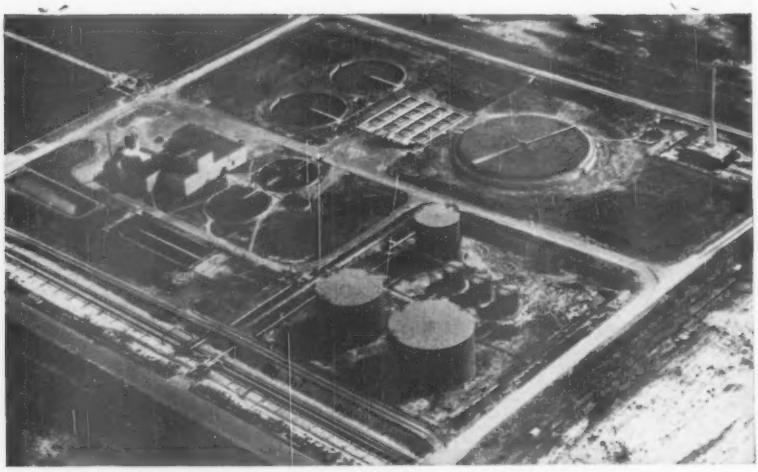
1005 SPENCERVILLE ROAD, LIMA, OHIO
415 S. ZANGS BLVD., DALLAS, TEXAS



Consulting Engineers: Bechtel Corporation, San Francisco, Calif.

HOW SHELL SOLVED A REFINERY WASTE DISPOSAL PROBLEM

Unique treatment plant meets strict requirements . . . using Dorr-Oliver equipment

In establishing its refinery near Anacortes, Wash., the Shell Oil Company faced strict requirements for control of pollution in an important commercial fishing and recreational area.

Requirements are met by efficient waste treatment facilities that handle all process and drainage waters from the refinery, as well as sanitary wastes. Operations include oil-water separation, chemical flocculation, biological treatment including trickling filtration, activated sludge and complete sludge handling. Virtual elimination of objectionable phenols is accomplished by utilizing a strain of bacteria specially adapted to phenol consumption. The excellent results achieved are shown in an analysis of the plant effluent, which averages only 7 ppm of oil and 0.15 ppm phenols, both well below the required State minimums.

Dorr-Oliver equipment installed includes two 60′ dia. Clariflocculators, a distributor for the 140′ dia. trickling filter and two activated sludge Clarifiers designed to handle 2000 gpm of effluent. Sludge handling equipment includes a 30′ dia. Dorr Thickener and two 8′ dia. x 12′ long Oliver Rotary Vacuum Precoat Filters.

For information on all waste treatment problems, write to Dorr-Oliver Incorporated, Stamford, Connecticut.

Dorrco and Clariflocculator — T. M., Reg. U. S. Pat. Off.

DORR-OLIVER
INCORPORATED
WORLD-WIDE RESEARCH — ENGINEERING — EQUIPMENT
STAMFORD • CONNECTICUT • U.S.A.

Sewage Works

FEASIBILITY OF CURVILINEAR ALIGNMENTS FOR RESIDENTIAL SANITARY SEWERS

By Harvey F. Ludwig

Consulting Engineer, Engineering-Science, Inc., Arcadia, Calif.

This discussion summarizes an evaluation of the use in the United States of curved or curvilinear alignments for residential sanitary sewers, as distinguished from the conventional practice wherein only straight runs are allowed between manholes. The study, undertaken on behalf of the Federal Housing Administration, was made over the period February through May 1959.* The primary objective was to ascertain the feasibility of curved alignments on the basis of actual experience in communities where such alignments have been used.

Although information was obtained on sanitary sewers of all sizes and for various locations throughout communities, the analysis focused on sewers serving essentially residential areas and within the range of pipe sizes generally associated with residential services, viz., from 8- to 12-in. diameter. Information was also obtained, when available, on the use of vertical curves in community sewer layouts.

The only previous study on curvilinear sewer alignments, known to this study group as the result of personal knowledge and a search of the literature, was that carried out by the Building Research Advisory Board (1). A review of the literature failed to turn up any additional reports specifically on curved sewers. It was learned, however, that in 1956 the Standards Committee of the Great Lakes and Upper Mississippi River Board of Engineers gave preliminary consideration to the possibility of establishing curved sewer standards.

Organization of Study

The study was initiated by a mail canvass to some 126 sanitary engineers throughout the country, primarily for the purpose of locating communities using curved sewers, but also for obtaining the opinions of these various individuals. Field visits were then made to the communities where curved sewers were known to have been used, totaling 66 in all, of which 43 were located in California. The total number of communities using or having used curved sewers in the United States is estimated at 200, i.e., the survey probably located about a third of the total, but the coverage in California is believed to be fairly complete.

Information was collected from each community on the following aspects:

1. History of curved sewer utilization.
2. Physical data on curved sewer installations.
3. Acceptance procedures (on completion of construction).
4. Location of sewer and of connections (after sewer is in use).

* A detailed report dated June 1, 1959, was filed with the Federal Housing Administration.

5. Construction costs (including contractor's costs, field engineering, and inspection).
6. Maintenance.
7. Hydraulic design.
8. Over-all evaluation of curved sewers.

In all cases the technique was first to establish a background picture of the sewerage practice at the community with respect to straight sewers, and then to establish the differences experienced with the curved sewers. The primary information was obtained in most instances from the community's supervisory sewerage engineer or official, but whenever possible supplementary data were obtained from any individual having knowledge of the system, including maintenance officials, consulting engineers, and contractors.

History of Curved Sewer Utilization

Early Practice

The conventional standards of Metcalf and Eddy (2), which have been widely used, are quoted in part as follows:

> No sewer which is so small that a man cannot enter it should have any curve or change in grade between manholes, as, otherwise, cleaning it may be difficult. Large sewers may be given such curves and changes in grade as conditions demand, but with small sewers the changes should be made by channels in the bottoms of the manholes, the loss of head due to the turning being compensated by an increased fall in the manhole.

As noted, the essential basis for the straight run requirement was that of cleaning or maintenance. Probably another factor influencing the acceptance of the straight-run standard was the general use in early days of grid street layouts; however, some communities having a large number of curved streets in hilly zones did use curved sewers, even in the early days, despite the straight-run standard. These earlier uses of curved runs often were associated with poor joints, and accompanying severe root penetration (trees being common in the hilly regions). The resulting maintenance difficulties naturally reflected unfavorably on the use of curved alignments.

Later Trends

Recent developments, mostly since World War II, have brought about a new interest in the use of curved sewers and now require a careful reevaluation of the bases for the conventional standards. These developments may be classified as follows:

1. Improvements in sewer maintenance equipment and techniques (3). Development of new equipment, particularly of flexible and powered rods and of rifled balls, has almost completely revolutionized sewer maintenance methods and makes it possible to maintain curves with little extra work.
2. Widespread use of curvilinear streets in new housing developments, and increasing redevelopment of already built-up areas, both creating an increasing number of instances where the use of curved sewers offers real economies.
3. Development of root-resistant joints.

The combination of these developments has resulted in significant and increasing use of curved alignments, particularly in areas undergoing rapid population growth.

Discussions with planning authorities indicate a significant change underway in the basic concept of subdivision street planning since World War II. Whereas previous subdivisions were largely limited, for reasons of economy, to relatively flat terrain and grid street layouts, the trend has been toward increasing use of curved streets not only because of the increasing scarcity of flat lands but also

because of the improved buying power of housing purchasers, and the increasing influence of governmental planning and financing agencies interested in improving all phases of home living. As a result, curvilinear patterns are now "standard" for many Southern California subdivision layouts, including those on flat terrain. The degree of curvature used depends primarily on topography, the sharper curves being needed in the more hilly terrains. Generally, where topography permits (where the mean gradient is less than 10 per cent) the most common design radius is 500 ft, as use of sharper curves tends to produce "pie-shaped" lots. Also, the practicable minimum radius (for movement of such traffic as moving vans) is 100 ft, the "comfortable minimum" is approximately 150 ft, and the most common curvature in hilly areas (mean gradient over 10 per cent) is about 200 ft.

There are no generally accepted standards for curved sewer design in use in the United States. Each community using curved sewers has fixed its own criteria. In Southern California the standards of the City of Los Angeles have been followed by many of the other communities, no doubt because of the vastly greater experience of Los Angeles than all the other cities in Southern California combined.

The present official position of the Federation of Sewage and Industrial Wastes Associations and of the American Society of Civil Engineers as expressed in the jointly-prepared "Sewer Design Manual" (4) is quoted as follows from Chapter 6, Section D:

> It is general practice to lay sewers in straight lines between manholes in sizes up to and including 2½ to 3 ft in diameter. In larger sewers, and especially sewers through which a man can walk, curves may be used as desired. In some places on the west coast the practice has been adopted in recent years of using simple horizontal or vertical curves of not less than 100-ft radius for all sewer sizes. Sewer maintenance men in that area have found no objection to such construction. The criterion on this point is to be able to operate sewer cleaning equipment in the length between manholes.

As previously noted, a committee of the Great Lakes and Upper Mississippi River Board of Engineers did consider, but decided against, adopting a set of standards for curved sewers. The only other evidence of interest in establishing such standards, discovered during the survey, was the current effort of the Texas State Department of Health. A tentative draft was proposed "Rules and Regulations Regarding Preparation, Submission, and Approval of Plans for Sewerage Systems," * contains the following references to curved sewers:

1. "Sewers shall be laid in straight alignments with uniform grade between manholes. However, where horizontal curvature must be used, the smallest radius of curvature shall be 100 feet."
2. "Manholes shall be placed . . . at each end of horizontal curves."

Analysis of Mail Inquiries

The replies from engineers throughout the country were generally similar in that, with a very few exceptions, curved sewers were endorsed by or positively considered only by those engineers having had specific experience with such installations, and this group of engineers represented an insignificant portion of the total. The attitude of engineers not having had personal experience ranged from one of no comment to outright disapproval and in general was on the cautious side. The main arguments advanced against the use of curvilinear alignments were: (*a*) increased difficulties in sewer maintenance, (*b*) inability to see through the line for purposes of acceptance and/or of maintenance, (*c*)

* These were reviewed at the Annual Meeting of the Texas Water and Sewage Works Assn.; College Station, Tex.; Mar. 1–6, 1959.

increased difficulties in locating the sewer or in locating wyes for connecting to the sewer, (*d*) increased difficulty in achieving proper alignment and grade during construction, and (*e*) inferior hydraulic properties.

Geometry of Curved Sewers

Savings in Manholes

By using curved sewers on curved streets it is possible to reduce the number of manholes and the length of pipe as compared with using straight runs only. The principal factors which determine the magnitude of the saving are the centerline radius and deflection of the street curve, the manhole spacing used on straight and curved reaches, and the effective street width (that portion of the right-of-way in which the sewer may be laid). In any actual case the saving also depends on the street alignment beyond the ends of the curve in question, the location of any essential manholes beyond the ends of the curve (at junctions, for example), and the location at which the curved sewer is to be placed in the street cross section.

Figure 1 illustrates the saving which may be made in number of manholes by using curved sewer instead of straight runs, as a function of curve deflection and radius. The graphs are only valid for a ratio of effective street width to manhole spacing equal to 0.07714, which corresponds to the Los Angeles County standards of 36-ft total street width (27-ft effective width) and 350-ft manhole spacing. They also involve assumptions that: (*a*) the same maximum manhole spacing is used on straight and curved lines, (*b*) the street remains straight for at least one manhole spacing at each end of the curve, (*c*) a curved sewer would follow the street centerline, and (*d*) there are no junction manholes on or near the curve. However, failure to fulfill any of these assumptions except the last would not significantly affect the results. The graphs, of course, represent an average manhole saving; in

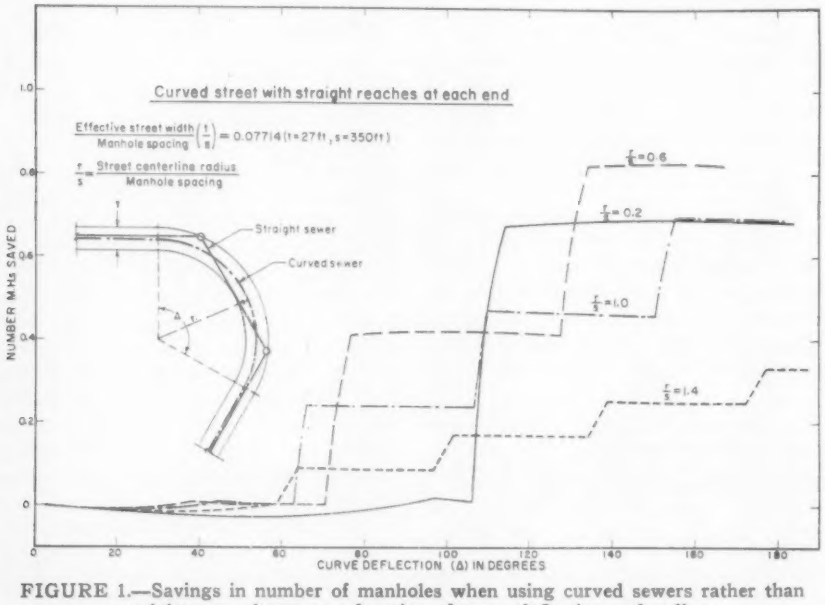


FIGURE 1.—Savings in number of manholes when using curved sewers rather than straight runs, shown as a function of curve deflection and radius.

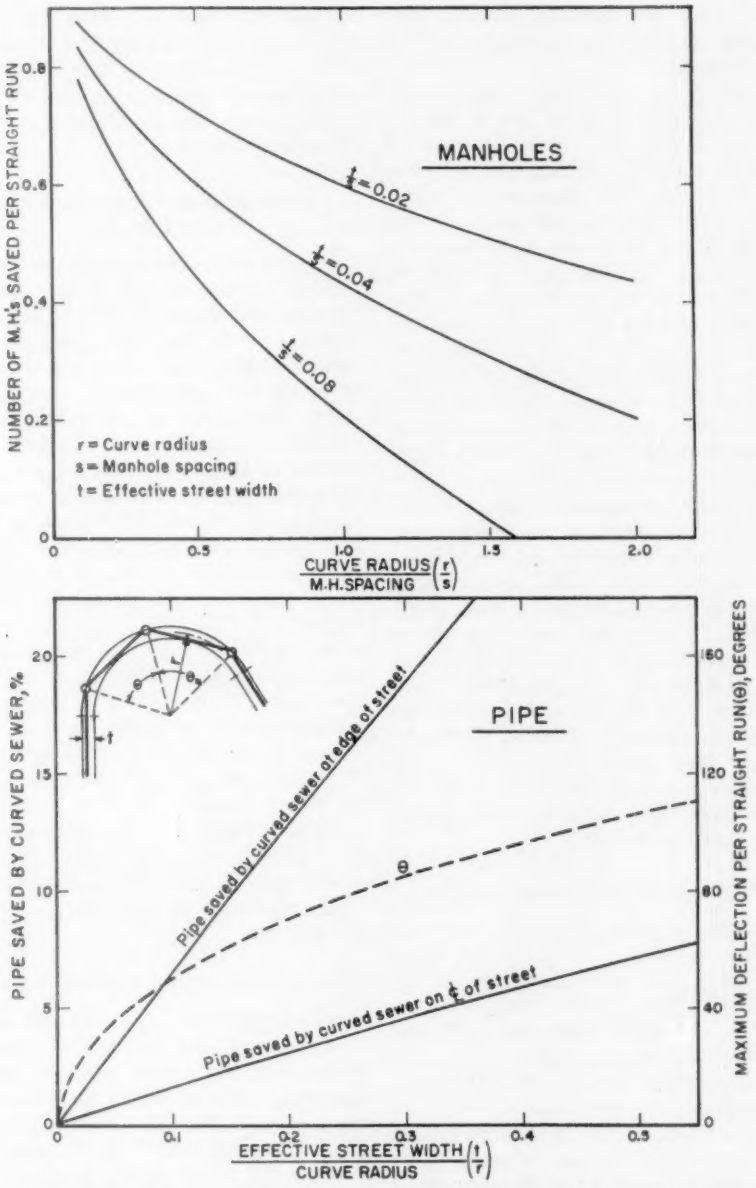


FIGURE 2.—Approximate number of manholes saved per unit of curve deflection as a function of radius, manhole spacing, and effective street width.

any particular case the number of manholes saved must be a whole number. For curves of small deflection a slight negative saving is indicated. It is due to the assumption that a curved sewer would follow the street center-

line, while the straight sewer is permitted to take the most economical configuration.

Figure 2 gives the approximate number of manholes saved per θ degrees of curve deflection as a function of radius, manhole spacing, and effective street width. The angle θ, the maximum deflection obtainable with a single straight run of sewer, is shown as a function of t/r, the ratio of effective street width to curve radius. The average number of manholes saved on a street curve of $(k\theta + \alpha)$ degrees of total deflection (k being an integer; $< 0 < \alpha < \theta$) is about $(k-1)$ times the value given on the curve for α less than about 20 degrees, and k times the curve value for greater values of α. For deflections less than θ, no manholes are saved, even though the most economical straight configuration requires a manhole at the center of the curve, because there is no reduction in spacing required. There are also some street configurations on which curved sewers would have less advantage than indicated by the graphs, such as some reverse curvatures, but these would be rather rare. Restrictions on the use of curves—requiring manholes at one or both ends, for example—would handicap them appreciably.

Savings in Total Pipe Length

Figure 2 also gives the per cent saving in pipe obtainable by using curved sewers as a function of the ratio of effective street width to curve radius. Plots are shown for both centerline and inside-of-curve alignment of the curved sewer. The difference is appreciable; for a street whose effective width is one-third of its radius, the centerline location saves only 5 per cent on pipe while 20 per cent is saved by following the edge.

Analysis of Community Data

The detailed data collected from the 66 cities contacted are summarized in Tables I, II, and III. The following discussion presents detailed analyses of the various factors influencing the use of curved sewers, arranged to correspond with the headings shown in the tabulations:

Geographical Distribution of Curved Sewers

Curved sewers are in common use in certain regions in the United States, but are used elsewhere only in isolated instances. In the west, regions of considerable curved sewer use are centered around Los Angeles, San Francisco, Portland, and Seattle. Midwestern regions using curves are Texas, Nebraska, Minnesota, and Illinois. In the northeast there are several isolated cities known to use curves, but in the south, other than in Texas, Shreveport, La., was the only one found. No curves were found in the Rocky Mountain States.

Of the 66 communities sampled, 22 were in Southern California, and 21 in Northern California. The sample of communities is weighted to some extent in favor of the West Coast areas because of more exhaustive canvassing in those regions; however, judging from the response to the queries made throughout the United States, the use of curves is in fact more widespread in California than in any other part of the country.

Reasons for Using Curved Sewers

Fundamentally, economy is the only reason for using curved sewers in preference to straight runs; however, there are many ways in which economy can be achieved through use of curves. Table IV summarizes the reasons advanced for using curves (by percentages of communities). Saving manholes was the most common reason given in all areas, and was stated by the majority of the communities. This reason is further augmented by those of saving utilities, keeping sewer in

TABLE I.—Summary of Community Field Reports From Southern California *

City or District	Populat. (×1,000) 1.	No. Curved Instal. 2.	Period of Use (19— to 19—) 3.	Where Used 4.	Reasons 5.	Pipe Material 6.	Type Joint 7.	Min Pipe Diam on Curves (in.) 8.	Radius Range (ft) 9.	Length Range (ft) 10.	Manhole Spacing Range (ft) 11.	Types of Curves Used 12.	Locat. of Sewer in St. 13.
Los Angeles	2,000	>1,000	46–59	NS	M, U	VC	C, HP	8	100–?	—	—	V, P: R, C	℄℄
Santa Barbara	56	310	55–59	NS	M, U	VC	C, CPI-2	8	100–2,000	—	350†	P: R, C, V, HV	℄℄
Los Angeles County	—	>100	54–59	D	U	VC	C	8	—	—	200†	V, No: R, C	All
San Diego	665	80e	84; 48–59	OT, H	H, U	VC	JC-60	8	60–?	—	~250†	V	‖℄℄℄℄
So. Laguna San. Dist.	—	60e	53	All	M	VC	C	8	50–300	30–400	160–600	R, C, No: V, HV	‖℄℄℄℄
Burbank	94	40	53–59	R, H	M, U	VC	C	8	90–?	—	350†	V, P: R, C, HV	℄℄℄℄
Long Beach	251	10e	44–59	R	M, U	VC	CPI-2	8	180–700	150–600	300†	V, No: R, C, HV	℄℄℄℄
San Bernardino	83	10e	45–59	NS	U, H	VC	JC-60, C	8	300–600	—	?–600	No: V, HV	‖℄℄
Fullerton	51	10	56	NS, D	U, M	VC	C	10	—	—	400†	R, No: V	Eas; All
Laguna Beach	9	8	56–59	H	M, CL	VC	HP, PI	8	250–700	—	—	V, P: R	℄, Sh
Glendale	96	7	57–59	H	U, M	VC	C	8	65–300	100–180	?–250	No: R, C, V, HV	Most ℄
E. San Bernardino Water Dist.	20	4	58	NS	U, M	VC	JC-60	6	210–800	115–165	—	No: V, HV	‖℄
Salton City	0.2	4	59	NS	M, CL	VC	C	6	500	—	—	—	RI.
Barstow	10	—	53–59	—	M	VC	C	8	230–?	—	250†	No: R, C, V, HV	℄℄
Victorville	3	4	57–59	NS	M	VC	C	8	300–600	275–315	—	V, No: R, C, HV	℄℄
Covina	17	2	59	D	IR, U	VC	C	8	100–200	50–200	50–200	No: R, C, V, HV	Sh
Julian San. Dist.	0.5	2	53	—	E	VC	—	—	1,200	500	—	V, No: R, C, HV	‖℄
Dana Point	1	—	58	All	M, E	VC	HP	8	—	—	—	—	℄
Oceanside	13	1	28	D	‖RW	VC	CPI-2	8	800	?–800	300	—	Sh
Brea	7	1	58	D	‖RW	VC	C	10	500	1,100	350–400	No: V	‖ Channel
Pomona	35	1	59	NS	H, M	VC	C	8	20	14	—	No: R, C, V, HV	—
West Covina	50	30	55–59	NS	M, U	VC	C	—	100–300	100–200	350†	V, P: R, C, HV	All

TABLE I.—*Continued*

City or District	Type House Connect.	Method Locating New Connect.	Acceptance Tests Used	Const. Cost Compar.	Insp. Cost Compar.	Field Engr. Cost Compar.	"n" Value Curved/ Straight	Min Design Veloc. (fps)	M. H. Head Loss Angle Pt./ Straight (ft)	Rec. M. H. Spacing Curved/ Straight (ft)	Rec. Min Curve Radius (ft)	Max All. Joint Pull (deg or in.)	Type Maint. Program
	14.	*15.*	*16.*	*17.*	*18.*	*19.*	*20.*	*21.*	*22.*	*23.*	*24.*	*25.*	*26.*
Los Angeles	St	OS, WT	Inf (in GW)	+0–15%	=	+2×	0.015	0.4‡	0.2/0.1	450	100	1 in.	Pr
Santa Barbara	Y	WT	Ex	=	MC	+10%	0.014	2	0.2/0.1	350	100	—	St
Los Angeles County	St	MM	Ex	=	=	+5%	0.013	1.5–2	0.2/0.1	350	—	5°	Ins
San Diego	Tp	—	Ex	+5–10%	+10%	+1–1.5×	0.013	0.4‡	S/S	250/350	—	3°	Pr
So. Laguna San. Dist.	Y	MM	B	+3%	—	—	0.013	2	S/S	300	None	—	Pr
Burbank	Tp	—	B	=	=	=	0.015	2	0.2/0.1	350	100	—	Pr
Long Beach	Y	MM	B	=	=	=	—	—	0.1/?	300	—	—	Pr
San Bernardino	Y	—	Ex	—	=	=	0.015	2	0.2/0.1	400	300	—	Pr
Fullerton	Tp	—	—	—	—	—	0.015	0.4‡	0.2/0.1	400	—	—	—
Laguna Beach	St	MPL	Ex	—	=	+little	—	—	—	250	250	—	Pr
Glendale	Y	WT	None	+0–15%	=	+30%	0.011	2.5	0.2/0.2	?/350	None	—	Pr
E. San Bernardino Water Dist.	Tp	—	Ex	=	=	=	0.015	2	0.2/0.1	400	200	—	Ins, Pr
Salton City	Y	MPL	Flow	—	—	—	0.013	—	0.1/?	400	—	—	—
Barstow	St	WT	Ex	=	=	=	0.013	2	0.2/0.2	250	200	—	St
Victorville	Tp	—	Ex	little less	=	=	0.013	2	0.2/0.2	300	200	—	St
Covina	—	—	Ex	=	=	=	0.013+/ 0.013	2/0.4‡	0.15/0.1	300–/300	None	—	Ins
Julian San. Dist.	Tp	—	—	=	—	+10%	—	—	—	350	—	—	—
Dana Point	—	—	—	=	=	+100%	0.013	—	0.1/?	350	—	—	—
Oceanside	—	Sur	—	—	—	—	—	—	—	—	—	—	Pr
Brea	None	—	Ex	—	—	—	0.013	1.5–2	S-0.15/S-0.15	—	250–300	—	St
Pomona	—	—	—	—	—	—	—	—	0.2/?	—	—	—	—
West Covina	St	MM, MPL, Mk	Ex	+little	=	+little	0.013	—	0.2/0.1	350	100	—	Ins

TABLE I.—*Continued*

City or District	Balling Curves 27.	Rodding Curves 28.	Bucketing Curves 29.	Topog. in Curve Areas 30.	Prevalence of Root Prob. 31.	Prevalence of Garbage Grinders 32.	Freq. of Clean. (times/yr) 33.	Maint. Cost ($ or men/mile) 34.	Over-all Maint. Exper. with Curves 35.	Prob. Locat. Sewer on Curves 36.	Prob. Locat. House Connect. 37.	Attitude Toward Curves 38.	Trend in Use of Curve 39.
Los Angeles	=	=	+	All	—	H	0.7–1	0.025	=	N	N	Ec	=
Santa Barbara	—	—	—	—	—	—	—	—	=	—	—	=	=
Los Angeles County	=	=	NUC	—	+	H	—	$140/0.015	=	N	+	Av	=
San Diego	NU	—	RU	H	+	H	0.75–3	$100	—	N	—	Sp	=
So. Laguna San. Dist.	+	+	NU	H	+	H	1	0.07	+	—	—	Av	Less
Burbank	=	=	RU	H, F	—	—	0.5	—	=	N	—	Ec	=
Long Beach	=	=	RU, +	F	—	—	0.25–1	0.019	=	N	N	Ec	=
San Bernardino	—	=	—	F	+	—	0.33	0.015	=	—	—	=	—
Fullerton	—	+	—	H	—	—	—	—	+	N	N	Av	=
Laguna Beach	NE	NE	NE	H	+	—	—	—	NE	N	N	Sp	+
Glendale	NU	NE	NE	H	+	H	1	0.017	NE	NE	NE	Sp	—
E. San Bernardino Water Dist.	NE	NE	NE	—	—	—	0.2	—	NE	—	—	=	—
Salton City	NE	NE	NE	F	—	—	—	—	NE	NE	NE	Ec	=
Barstow	=	=	NU	H	+	—	—	$50/0.018	=	N	—	Ec	—
Victorville	NU	Less work	—	—	—	—	—	—	=	—	+Y's	=	—
Covina	=	=	NUC	—	—	—	—	—	=	—	—	Sp	=
Julian San. Dist.	—	—	—	H	—	—	—	—	=	—	—	—	—
Dana Point	—	—	—	—	—	—	—	—	—	—	—	—	—
Oceanside	—	=	—	—	—	—	—	—	=	+	+	P	P
Brea	—	—	—	F	—	—	—	—	NE	—	—	Ec	—
Pomona	—	—	—	—	—	—	—	—	—	—	—	—	—
West Covina	=	=	NUC	—	—	—	—	—	=	N	N	Ec	+

* See Appendix for explanation of aymbols used in tables.

† Average rather than range.

‡ Minimum slope in per cent for 8-in. sewers.

TABLE II.—Summary of Community Field Reports From Northern California *

City or District	Populat. (×1,000)	No. Curved Instal.	Period of Use (19— to 19—)	Where Used	Reasons	Pipe Material	Type Joint	Min Pipe Diam on Curves (in.)	Radius Range (ft)	Length Range (ft)	Manhole Spacing Range (ft)	Types of Curves Used	Locat. of Sewer in St.
	1.	*2.*	*3.*	*4.*	*5.*	*6.*	*7.*	*8.*	*9.*	*10.*	*11.*	*12.*	*13.*
Stege San. Dist.	24	240e	25–49	H	E, M	VC	C	6	350†	350†	300†	R	Pk, RI.
Central Contra Costa San. Dist.	100	200e	44–52	H	M, E	VC	C, HP	6	50–?	25–?	500†	R, V	℄
San Carlos	20	150e	30–59	All	M	VC	C, PI	6	100–?	375†	300†	R	‖℄
Oakland	405	100e	10–59	Lake, H	E, U, M	VC	C, HP, PI	6	22–?	30–300	200–300	R, V, HV	‖℄
Sacramento	158	100e	57–59	NS	M, U	VC	CPI-2, JC-60, PI	6	500†	300†	300†	No: V	‖℄
Salinas	21	100e	52–59	NS	M, U	VC	JC-60	8	150–1,200	50–400	350†	V, No: R	‖℄
San Pablo San. Dist.	18	100e	25–59	H	M	VC	C	6	150†	150†	185–392	R, V	℄
San Anselmo	10	100e	10–59	H	M	VC	C, HP, PI	6	50–?	—	?–325	No: R, C, V, HV	All
Palo Alto	41	80e	50–59	All	IR, M	VC	CPI-2	6	115–800	300–1,200	130–460	R, V	℄
San Andreas	1	80e	53–59	H	E, Ob	C, T	JC-60, TR	6	60–1,000	—	300†	R, V	Eas
Belvedere	1	>50	90–00	H	IR	VC	C	5	40–2,000	—	1,000–2,000	R, V, HV	Gtr
Mill Valley	8	50e	00–59	All	M	VC	C, PI	6	50–?	—	?–5,000	R, V, HV	All
Berkeley	118	30+	10	H	M	VC	C	6	20–400	—	60–800	R, No: V	‖℄
Redding	13	30	57–59	NS	M, E	VC, T	PI, TR	6	120–900	55–180	—	V, HV	—
Carmel	4	25e	50–59	H	M, IR, Ob	VC, T	C, BR, PI	6	50–400	—	—	R, V	Pk, ‖℄
Redwood City	39	12	57–59	H	M	VC	CPI-2	6	100–300	—	110–300	No: V, HV	℄
Los Altos	21	7	57–59	NS	M	VC	BR	6	200–475	300–400	100–300	No: R, C, V, HV	℄
San Rafael	15	5+	85–56	H	M, E	VC	C	6	100–?	—	?–600	No: R, C, HV, P: V	℄
Corte Madera	3	?	98–55	H	IR	VC	C	5	30–3,000	—	—	No: V	℄
Novato San. Dist.	5	2	50–59	All	M, U	VC	CPI	8	200–360	200–300	—	R, No: V	All
Valley Springs	0.5	3	57–59	All	PA, Ob	VC	JC-60	6	200	100–200	300†	No: R, C, V, HV	Eas

TABLE II.—*Continued*

City or District	Type House Connect.	Method Locating New Connect.	Acceptance Tests Used	Const. Cost Compar.	Insp. Cost Compar.	Field Engr. Insp. Compar.	"n" Value Curved/ Straight	Min Design Veloc. (fps)	M. H. Head Loss Angle Pt./ Straight (ft)	Rec. M. H. Spacing Curved/ Straight (ft)	Rec. Min Curve Radius (ft)	Max All. Joint Pull (deg or in.)	Type Maint. Program
	14.	*15.*	*16.*	*17.*	*18.*	*19.*	*20.*	*21.*	*22.*	*23.*	*24.*	*25.*	*26.*
Stege San. Dist.	Y	—	B, Ex	—	—	—	0.013	2	—	300	—	—	St
Central Contra Costa San. Dist.	Y	Inst	B, Ex	=	=	+0–10%	0.013	2, 0.33‡	0.1/?	—	500	—	Pr
San Carlos	St	Mk	B	+5%	=	=	0.015	2	0.2/0.2	300	100	—	St
Oakland	St, Tp	Mk	Ex, B, Gl	=	=	=	0.013	2	S/S	200–300	None	1°	Ins, St
Sacramento	—	Mk	Ex	=	=	=	0.013	2	0.2/?	300	200	—	St
Salinas	St	Map, Mk	Gl, B	=	=	=	0.013	1.75	0.1/?	700–/700	150	—	Fl, Ins
San Pablo San. Dist.	Tp	—	Ex, Gl, or B	—	=	=	0.013	2	—	—	None	—	Fl, Ins
San Anselmo	St	Mk	Ex, Gl, or B	=	=	=	0.013	2	S/S	800	50	—	Pr
Palo Alto	St	Mk	B, Ex	=	=	=	0.013	2	0.2/?	500	100	3°	St
San Andreas	Tp	—	B	—	—	—	0.013, 0.011	2	0.1–0.2/?	300	50	—	Ins, St
Belvedere	Tp	—	Ex	—	—	—	?/0.013	2	S/S	?/400	—	—	St
Mill Valley	Y, Tp	—	Ex, Gl, Fl	=	=	=	0.013 +/ 0.013	2	0.2/?	400/450	None	—	St
Berkeley	Y	Soil color	—	—	—	=	0.013	2.5	0.1/?	300	—	—	Pr
Redding	St	Mk, Map	B, Ex	=	=	=	0.013	2	0.2/?	300/400	200	—	Pr
Carmel	St	Mk	Fl, Ex	=	=	=	0.013	2	0.2/?	300–400/450	None	—	Ins
Redwood City	Tp	—	Ex	=	=	=	Not used	—	S/S	300	300	—	St
Los Altos	St	Mk	Ex, B	=	=	+little	0.015	2	0.15/?	350	None	—	St
San Rafael	Y	Dig	Gl, Ex	—	—	—	?/0.011	2	0.1/?	?/300	—	—	St
Corte Madera	Y	Inst	B, Ex	—	—	—	?/0.013	2	0.2/?	?/250	None	—	St
Novato San. Dist.	—	Map	Ex	=	=	=	0.013	2	S/?	300	None	—	St
Valley Springs	Y	Map	B	=	=	=	0.013	2	0.1–0.2/?	300	—	5'3", 3'2"	St

TABLE II.—*Continued*

City or District	Balling Curves	Rodding Curves	Bucketing Curves	Topog. in Curve Areas	Prevalence of Root Prob.	Prevalence of Garbage Grinders	Freq. of Clean. (times/yr)	Maint. Cost ($ or men/mile)	Over-all Maint. Exper. with Curves	Prob. Locat. Sewer on Curves	Prob. Locat. House Connect.	Attitude Toward Curves	Trend in Use of Curve
	27.	*28.*	*29.*	*30.*	*31.*	*32.*	*33.*	*34.*	*35.*	*36.*	*37.*	*38.*	*39.*
Stege San. Dist.	—	+2×	—	H	—	—	—	—	+	+	+	P	P
Central Contra Costa San. Dist.	—	+25%	—	H	+	—	0.2	0.031	+25%	—	+	Av	Less
San Carlos	—	=	—	H, F	+	—	—	$80	=	=	=	=	=
Oakland	—	—	—	H	—	—	—	—	+100%	—	—	Av	Less
Sacramento	=	=	=	F	—	—	—	—	=	—	—	=	+
Salinas	NU	NE	NU	F	N	—	—	—	=	N	N	=	+
San Pablo San. Dist.	—	=	=	H	+	—	1	0.04	=	—	—	Av	Less
San Anselmo	—	=	—	H	+	—	1	0.033	=	N	N	Ec	+
Palo Alto	—	—	—	F	+	—	—	—	=	N	N	=	+
San Andreas	—	+little	—	H	+	—	—	—	=	—	—	=	=
Belvedere	—	=	—	H	+	—	—	—	=	N	—	—	Disc.
Mill Valley	NU	=	—	H, F	—	—	—	0.05	=	—	=	Ec	—
Berkeley	—	+	—	H	+	—	0.7–2	—	+	+	—	P	P
Redding	—	=	—	H	—	—	1	—	=	—	N	Nec	+
Carmel	—	=, >200'R	—	H	+	—	—	0.05	=	—	—	=	+
Redwood City	—	=	=	H	—	—	—	—	=	—	—	=	+
Los Altos	—	—	—	—	—	—	—	—	=	N	N	=, >500'R	+
San Rafael	—	=	—	H	+	—	—	—	=	+	+	P	P
Corte Madera	—	+	—	H	+	—	—	—	+2×	N	N	P	P
Novato San. Dist.	=	=	—	—	—	—	—	—	=	NE	NE	Av	=
Valley Springs	—	—	—	—	—	—	—	—	—	N	N	=	+

* See Appendix for explanation of aymbols used in tables.

† Average rather than range.

‡ Minimum slope in per cent for 8-in. sewers.

TABLE III.—Summary of Community Field Reports From the United States Exclusive of California *

City or District	Populat. (×1,000) 1.	No. Curved Instal. 2.	Period of Use (19— to 19—) 3.	Where Used 4.	Reasons 5.	Pipe Material 6.	Type Joint 7.	Min Pipe Diam on Curves (in.) 8.	Radius Range (ft) 9.	Length Range (ft) 10.	Manhole Spacing Range (ft) 11.	Types of Curves Used 12.	Locat. of Sewer in St. 13.
Portland, Ore.	500	380e	25–45	H	M	VC, C	C	8	50–?	50–?	?–700	R, V, HV	℄
Cedar Hills, Ore.	6	49	54–59	H	OR	C, T	C, RR, TR	6	117–?	650†	400–500	R	Pk
Sunnyside, Wash.	5	10	55–59	H	M, PA	C	C, JC-60	8	100–400	200–300	400†	R, V	Most ‖℄
Beaverton, Ore.	5	7	55–59	H	M, PA	T	TR	6	85–1,500	100–420	400–500	R	Sdk
Medford, Ore.	25	5	55–59	H	M, U	C	BR	8	120–1,000	260–470	500†	R, V, HV	All
Bothell, Wash.	1.5	3	58–59	—	OR	C	RR	8	600–700	100–800	300–400	V, R	Sh, ‖RR
Republic, Wash.	7	3	58–59	—	E	C	JC-60	8	230–500	—	350†	R, V	—
Des Moines Sewer Dist., Wash.	1	1	58	R	M	T	TR	8	100	—	275–360	V	Sh
Kenmore Sewer Dist., Wash.	—	1	58	R	M	T	TR	8	400	—	400†	No: R, C, V, HV	‖℄
Forth Worth, Texas	340	800e	20–59	NS	PA, M, U, H	C, VC	HP, C	6	25–?	—	500–1,000	R, V, HV	‖℄
Dallas, Texas	460	—	30–59	Most NS	PA, M, U	C	RR	6	125–1,700	—	?–1,900	R, V, HV	℄
Austin, Texas	200	~160 mi.	35–59	NS	PA, E	C	C, HP	6	85–2,000	—	?–600	R, V, HV	‖℄
Shreveport, La.	150	500e	46–59	NS	OR, M, PA	VC	HP, PI	8	120–?	—	400–500	HV, No: R	Pk
Lincoln, Nebr.	110	—	00–59	—	M	VC	C, HP, PI	—	50–?	—	—	No: V	—
Beatrice, Nebr.	14	60	88–59	All	M	VC	CPI-2	8	60–?	—	?–800	—	Bends
Minneapolis, Minn.	600	75	80–59	H	PA, H	VC	C	9	22–?	—	135–150	No: V, R	℄
Golden Valley, Minn.	12	Many	00–59	H	U, M, H	VC	JC-60	8	22–?	—	250†	R, No: V	—
Elk Grove Village, Ill.	5	100e	56–59	NS	OR, M	VC	PI	8	150–1,500	—	200–385	No: V	Pk
Glenview, Ill.	12	75e	54–59	Most NS	OR	VC	PI	—	190–?	—	300–400	P: C	Pk
Highland Park, Ill.	20	—	?–59	NS	U	VC	PI	8	—	—	400†	—	‖℄
Richmond, Ind.	40	1	"Old"	—	H	VC	C	10	50	—	—	No: R, HV	—
Waterbury, Conn.	115	20	39–59	H	U, M	VC	HP	8	120–500	—	200†	No: R, V, HV	℄
Concord, N. H.	28	5	55–59	NS	U	VC, T	HP, TR	8	75–?	—	—	—	℄

TABLE III.—*Continued*

City or District	Type House Connect.	Method Locating New Connect.	Acceptance Tests Used	Const. Cost Compar.	Insp. Cost Compar.	Field Engr. Cost Compar.	"n" Value Curved/ Straight	Min Design Veloc. (fps)	M. H. Head Loss Angle Pt./ Straight (ft)	Rec. M. H. Spacing Curved/ Straight (ft)	Rec. Min. Curve Radius (ft)	Max. All. Joint Pull (deg or in.)	Type Maint. Program
	14.	*15.*	*16.*	*17.*	*18.*	*19.*	*20.*	*21.*	*22.*	*23.*	*24.*	*25.*	*26.*
Portland, Ore.	St	MM	Ex	—	=	=	0.015	San, 2; Com, 3	0.33/0.33	250	—	—	Pr
Cedar Hills, Ore.	St	Mk, Rec	Ex	=	=	=	0.015, 0.011	2.5, 0.4‡	0.2/?	450	—	—	None
Sunnyside, Wash.	—	MM, MPL	Ex, B	—	=	=	0.013	2.25, 0.4‡	0.1/?	400	100	—	Fl
Beaverton, Ore.	St	Map	Ex	=	=	=	0.011	2.5, 0.22‡	0.2/?	450	None	—	St
Medford, Ore.	St	Mk	Gl, Ex	=	=	=	0.013	2, 0.4‡	0.1/?	500	None	—	Pr
Bothell, Wash.	Y	Map	Ex, B	=	=	=	0.013	2.25	0.1/?	—	None	—	Fl
Republic, Wash.	Y	Map	Ex, B	=	=	=	0.013	2.24	0.1/?	400	100	—	St
Des Moines Sewer Dist., Wash.	—	—	B, Inf	—	=	=	=	—	0.1/?	?/400	—	—	Fl
Kenmore Sewer Dist., Wash.	—	—	B, Inf	—	=	=	=	—	0.1/?	400/650	—	—	Fl
Forth Worth, Texas	Tp	—	None	=	=	+10%	0.011	2	S/S	—	60	—	Ins
Dallas, Texas	Y	Map, Ins	Ex	=	=	=	None	1.5–2	0.1–0.2/S	—	—	—	St
Austin, Texas	Tp	—	Inf	little less	=	+20%	0.013	2	0.08/S	?/500	150	—	Pr, St
Shreveport, La.	Y	MPL	Insp	=	=	=	0.015	1.5–2	—	400	—	—	St
Lincoln, Nebr.	—	Rec	—	+little	—	—	—	—	—	—	100	—	—
Beatrice, Nebr.	Tp	—	None	—	=	+10%	—	—	S/S	400	—	—	Pr
Minneapolis, Minn.	Y	—	None	=	None	=	0.013	3	S/S	150/200	150	—	Pr
Golden Valley, Minn.	Y	Mk	Ex	=	=	=	0.013	2	S/S	250/330	None	—	Pr
Elk Grove Village, Ill.	Y	MPL	Ex	=	=	+little	0.013	2.3	0.2/?	250/400	—	—	St
Glenview, Ill.	Y, St	MM, MPL	None	=	=	—	—	2	—	400	200	—	St
Highland Park, Ill.	Tp	—	Ex	=	—	—	—	—	—	400	—	—	—
Richmond, Ind.	—	—	Inf	—	—	—	—	—	—	?/300	—	—	—
Waterbury, Conn.	Y	MM	Inf	=	=	+little	0.015	0.8‡	0.1/0.1	200	120	—	St
Concord, N. H.	Tp	OS	Ex	=	+	+10%	0.013, 0.011	2	S/S	400	75	—	Pr

TABLE III.—*Continued*

City or District	Balling Curves	Rodding Curves	Bucketing Curves	Topog. in Curve Areas	Prevalence of Root Prob.	Prevalence of Garbage Grinders	Freq. of Clean. (times/yr)	Maint. Cost ($ or men/mile)	Over-all Maint. Exper. with Curves	Prob. Locat. Sewer on Curves	Prob. Locat. House Connect.	Attitude Toward Curves	Trend in Use of Curve
	27.	*28.*	*29.*	*30.*	*31.*	*32.*	*33.*	*34.*	*35.*	*36.*	*37.*	*38.*	*39.*
Portland, Ore.	=	=	=	H	+	—	—	—	=	N	N	P	P
Cedar Hills, Ore.	—	—	—	H	—	—	—	—	=	—	—	Ec	+
Sunnyside, Wash.	—	=	—	H	—	—	—	—	=	—	—	Av	+hills
Beaverton, Ore.	—	—	—	H	+	—	—	—	=	—	—	Ec	+
Medford, Ore.	—	—	—	H	+	—	—	—	=	N	N	Av	=
Bothell, Wash.	—	—	—	—	—	—	—	—	=	—	—	Av	=
Republic, Wash.	—	—	—	—	—	—	—	—	=	—	—	Sp	=
Des Moines Sewer Dist., Wash.	—	—	—	—	—	—	—	—	=	—	—	Ec	—
Kenmore Sewer Dist., Wash.	—	—	—	—	—	—	—	—	=	—	—	Ec	—
Forth Worth, Texas	NU	—	—	—	+	H	—	—	+<25R	N	—	=	=
Dallas, Texas	—	=	=	—	+	—	—	—	=	N	N	=	=
Austin, Texas	=	=	=	—	+	H	—	0.025	=	N	—	Ec, >200R	—
Shreveport, La.	NU	=	—	—	+	—	—	$148	=	N	N	=	+CS
Lincoln, Nebr.	—	=	—	—	—	—	—	—	=	—	—	Ec	=
Beatrice, Nebr.	—	=	—	F	—	H	—	—	=	—	—	Ec	=
Minneapolis, Minn.	= (Disk)	—	—	H	+	L	—	—	=	N	N	Ec	=
Golden Valley, Minn.	—	—	—	—	—	—	—	—	—	N	N	Ec	=
Elk Grove Village, Ill.	NU	=	RU	F	+	—	—	—	—	N	N	Ec	=
Glenview, Ill.	NU	=	+	F	+	L	—	—	=	N	N	=	=
Highland Park, Ill.	–	—	—	—	—	—	—	—	—	N	—	=	=
Richmond, Ind.	–	—	—	—	—	—	—	—	+	—	—	P	P
Waterbury, Conn.	NU	—	RU	H	—	L	—	—	—	N	N	Ec	=
Concord, N. H.	NU	=	—	—	+	—	—	$38	=	N	—	=	+

* See Appendix for explanation of symbols used in tables.

† Average rather than range.

‡ Minimum slope in per cent for 8-in. sewers.

TABLE IV.—Summary of Reasons for Use of Curved Sewers

Reason	Area		
	Southern California	Northern California	All Other States
Save manholes	71	81	61
Avoid utilities	57	19	9
Save excavation	10	29	30
Maintain parallel alignment in street	0	5	0
Keep sewer in roadway	10	19	0
Keep sewer in parking strip	0	0	22
Avoid obstructions	0	14	0
Maintain good hydraulic properties	14	0	13
Keep sewer out of curved right-of-way	10	0	0
Permit curved property lines	10	0	0

roadway, keeping sewer in parking strip, avoiding obstructions, and keeping sewer out of curved right-of-way, since it was generally understood that such objectives were to be accomplished without using an excessive number of manholes.

Avoiding utilities was a major consideration in Southern California, but was not so widely mentioned in the other areas. Saving excavation was especially important in hilly communities. In some hillside communities curves were used on curved streets where only the houses on the upper side were served—this permitted use of a shallower sewer depth and, by locating the sewer toward the upper road edge, shortened the lengths of the house connections.

Curve Shapes, Dimensions, and Alignments

In general, curves were constructed using pipe of the same size as that used on straight sewers. The curve radii encountered ranged from 20 to 2,000 ft, and averaged about 300 ft. The sharp radii of 20 to 40 ft were used primarily on curves connecting laterals to main sewers, and were constructed of beveled pipe. Radii of 50 ft or more were invariably obtained by pulling the pipe at the joint. The length of curved runs varied between 15 and 1,200 ft, and averaged about 250 ft. The lengths were fixed largely by necessity rather than by design restrictions. Minimum manhole spacings were generally the same for curved as for straight alignments.

The curves encountered were classified into simple horizontal, reverse horizontal (S-shaped, without a manhole at the inflection point), compound (curves with changing radius), vertical, and those with combined horizontal and vertical curvature. In general, some cities employing curved sewers restrict the use of curves between manholes to simple horizontal curves, whereas others have had satisfactory experience with reverse curves, compound curves, horizontal and vertical curves in combination, and curves with straight sections at one or both ends. Where grades are relatively steep, all types of curves generally meet with satisfaction; where grades are flat (and periodic cleaning is likely to be required) reverse curves should be avoided because of increased difficulties in rodding and scraping. Vertical curves, although there is less occasion for them than for horizontal curves, have been more freely used because their angle of deflection is usually small. Combined horizontal and vertical curvature permits simplified construction in hilly terrain, and there seems to be little justification for prohibiting such combinations.

With respect to alignment, the positioning of a curved sewer within a curved street varied from community to community. Table V shows the percentages of distribution, by regions, for communities having curved sewers in various locations. The most common location was on the street centerline, but other locations in the right-of-way parallel to the centerline were also

widely used. Frequently the position of the sewer was limited by existing or proposed water, gas, power, and telephone conduits which also had to be fitted into the street cross section. These utilities are normally placed in the parking strip or in the roadway near the edges, and parallel to the centerline, leaving room for the sanitary and storm sewers near the center of the section. Another advantage in maintaining a centerline or parallel alignment is that future uncertainties about the location of the sewer are reduced or eliminated.

TABLE V.—Summary of Locations of Curved Sewers with Regard to Streets

Location	Area		
	Southern California	Northern California	All Other States
Street centerline	41	33	26
Parallel to centerline	23	29	22
Shoulder or parking strip	14	14	26
Easements	9	14	0
At sewer junctions	0	0	9
Anywhere on street	18	19	17

House Connections

Three procedures are commonly used in providing for future house connections to sewers: (*a*) tapping the sewer, i.e., leaving no wyes, thus requiring that future connections be made with saddles; (*b*) leaving a wye in the sewer at regular intervals or at whatever positions judged best to receive future connections; and (*c*) laying the house sewers to the curb or property line. In no city was the procedure used on curved sewers different from straight sewer practice.

Some communities reported problems in locating wyes and other connections to sewers because of inadequacies of maps, but usually such troubles existed with straight and curved lines to the same degree. Approximately 43 per cent of all communities positively reported no additional location problems on curves, and 9 per cent indicated difficulties of some sort. Of those reporting extra difficulties on curves, however, nearly all were making their connections to wyes in the sewer.

On curves the location of wyes is complicated because the position of the pipe cannot be determined by direct measurement between manholes. Even if it is known that the pipe runs on or parallel to the street centerline, measurements given by stationing must be made along the curve, either as a series of short chords or by laying the measuring tape loosely on the ground. Actually, such curvilinear measurements are used in some communities, apparently without difficulty; usually, however, the distance to be measured is less than 200 ft. In other cities the locations of wyes on curved sections of sewer are recorded as offsets from some line which can be conveniently laid out in the field. Usually a line between two manholes enclosing the curve is used, but it may be a tangent, and occasionally the locations are referenced to buildings or other permanent structures.

Acceptance Procedures

Tests and criteria for accepting sewers varied widely, ranging from no tests at all (i.e., dependence was placed solely on good inspection during construction) to various leakage tests. The distribution of procedures used is shown in Table VI. Exfiltration tests were the most popular acceptance procedures, and in all cities using an exfiltration test the same procedure was used on straight and curved reaches.

Visually sighting through the line, commonly known as "glassing," "lamping," or "flashing," was frequently performed as part of the acceptance procedure for straight runs. Since glassing is impossible with curved sewers, the reporting individu-

TABLE VI.—Summary of Acceptance Procedures for Sewers (by Percentages)

Acceptance Procedure	Area			
	Southern California	Northern California	Oregon and Washington	Other States
Exfiltration test	50	76	78	36
Passing ball	14	62	55	0
Infiltration test	5	0	22	14
Flushing and flow continuity	5	10	0	0
Glassing (straight line only)	0	29	11	0
None	5	0	0	36

als were therefore asked for their opinions of the value of the procedure. Most agreed that glassing was a convenience, but that it was not essential and should not be seriously considered as an argument against curved sewers. In order to compensate for not being able to see through curved lines, many communities specified that a free or secured sewer ball be passed through the line under the impetus of head built up by running a fire hose into the upstream manhole. This procedure was also required for straight lines in many places, as a means of insuring that no foreign objects were in the lines when accepted from the contractor, and that the joints were clean inside the pipe.

Construction Costs

Contractor's Costs

A large majority of the cities visited reported no increase in construction cost for curved as compared to straight sewers. The cities which did report increased costs for curves all used curves with radii of 100 ft or less; however, many cities, especially outside Southern California, used equally small radii with no apparent extra cost. While the unit construction cost of short-radius curves is almost certainly greater than for straight lines, most sewer construction jobs consist of only a small percentage of curves, and any increase in price due to curvature would be difficult to detect because of the many other cost-determining variables. Accordingly, an independent analysis was made of this subject based on estimating the costs of each of the work components undertaken by the contractor, with the unit costs evaluated through consultation with several sewer contractors. In brief, this analysis indicates that, exclusive of manholes, the contractor's unit costs for labor and equipment are not greater for curves where the radius of curvature is 200 ft or more. Below 200-ft radius the unit cost of curved sewers is greater, the additional amount increasing with shorter radii, and below 100-ft radius the additional amount increases rapidly. The extra costs are due primarily to increased work in excavation, fine grading, and laying and jointing. Under ordinary California conditions for an 8-in. sewer for a new subdivision, the extra costs for radii of 150, 100, and 50 ft are of the magnitude of $0.08, $0.17, and $0.36 per ft, respectively.

Field Engineering Costs

Increases in field engineering costs due to curves were, again, very difficult to ascertain from the community data (which reported increases ranging from zero to 300 per cent). Generally, greater increases were stated by those cities doing their own field engineering work. Since field engineering costs represent a small percentage of the total sewer construction costs, any small increases due to curvature would be difficult to detect in over-all construction cost data. Moreover, since field engineering is often done by contract, the fact that the engineering fees are established as more-or-less fixed percentages of the total construction cost would tend to result in the engineer absorbing any extra costs without

any increase in his contract fee. Accordingly, an independent analysis was made of field engineering costs based on estimating unit costs of each of the engineer's work components. This study indicated that field engineering costs are greater for curved than for straight runs, and that the estimated average increase (for a 100-ft radius of curvature) is about 100 per cent (representing an increased cost of the magnitude of $0.10 to $0.20 per ft).

Inspection Costs

It was almost unanimously reported that field inspection costs are equal for straight and curved sewer construction. Although curved runs require more attention by the inspector per foot, the cost of inspection is not increased except to the extent that more time may be required for construction of the job. Since curves eliminate some manholes and avoid utilities, the overall effect of curves generally should be to shorten job time and hence reduce inspection costs. Where inspectors are paid by salary, this should result in some savings. Where inspection is paid as a percentage of the contract construction cost, no change in costs for inspection would appear in the bookkeeping.

Summarized Cost Considerations

Offsetting the increases noted above (in the contractor's cost and in field engineering) are the following savings obtainable through use of curves:

1. Manholes. Assuming an average saving of one-third of the total number of manholes (at a radius of 100 ft), the reduction in costs will be of the magnitude of $0.30 per ft.

2. Utilities. The savings due to avoiding utilities may often be of substantial magnitude transcending the other factors involved.

3. Length of sewer. As noted previously, the total length of a curved run is estimated to range from 5 to 20 per cent less than for a zigzagged group of straight runs. This means an equivalent saving, for 8-in. pipe in new subdivisions, of not less than $0.20 per ft considering both labor and materials, and in many instances the savings would be much more (when the sewer follows the edge of the curved street).

4. House services on hillside lots. Sewers on curved hillside streets commonly serve only the homes on the upper side. In such instances curved sewers achieve real economies over zigzagged straight runs in two ways: (*a*) with the zigzag sewer, greater depths are required, in order to serve the home on the far side, and (*b*) by curving the sewer along the upper edge of the street considerable lengths of house sewers are saved.

In summary, the extra costs involved in the use of curved sewers on curved streets are more than offset by the savings, particularly in hilly terrains. Use of curved sewers is also indicated in situations where extensive relocation of utilities would otherwise be required.

Maintenance

Maintenance is a prime factor affecting the feasibility of curved sewers, because even a slight increase in maintenance costs will in the long run nullify appreciable savings in construction costs.

The simplest type of maintenance program is one in which stoppages are cleaned as they occur and are reported. Since the stoppage generally makes itself known by the appearance of some disagreeable nuisance, many communities undertake to prevent their occurrence through some sort of preventive action. This may be periodic flushing of sewers, regular inspection at manholes to detect incipient stoppages, or a full-scale program in which all lines are regularly balled or rodded. Table VII shows the percentage distribution

TABLE VII.—Summary of Maintenance Procedures (by Percentages)

Type of Program	Area			
	Southern California	Northern California	Oregon and Washington	Other States
Preventive	46	19	25	36
Inspection	18	14	0	7
Flushing	0	10	50	0
Stoppage	18	57	13	36
Not reported	18	0	12	21

TABLE VIII.—Summary of Cleaning Experiences for Curved Sewers (by Percentages)

Experience	Method		
	Balling	Rodding	Bucketing
No difficulty on curves	75	68	46
No experience on curves	19	11	31
Some additional trouble on curves	6	21	23

of communities practicing each of these procedures. It will be noted that the Southern California area is characterized by preventive programs, in contrast to Northern California where stoppage programs were the rule. The difference between the two California regions is largely explained on the basis of their relative slopes; the flat grades in Southern California make preventive cleaning more desirable.

The experience of all reporting communities in cleaning curved sewers by different methods is summarized in Table VIII. Only seven communities, all in California, reported really significant difficulties with maintenance on curves. In considering them individually to determine any common sources of trouble, it was found that all had some curves of less than 100-ft radius, and that all used mortar joints. Four of the systems were constructed some 50 years ago; two of the recent systems were built under economic stress and employed manhole spacings up to 600 ft; five of the systems are in areas subject to root intrusion; and six gave evidences of lax inspection during construction.

In summary, sewer maintenance officials who have had experience with curved sewers prefer straight runs as simpler to maintain, but generally agree that curves can properly be used in situations where their use results in appreciable savings in construction costs. With modern equipment curved sewers are readily balled and rodded, and, although bucketing is more difficult and hazardous with curves, bucketing is rarely required in residential sanitary sewers which have been properly designed and constructed. Also, by reducing the number of manholes, curves reduce the instances of sewer maintenance difficulties associated with structures (e.g., release of gases and dumping of debris). Maintenance problems with curved sewers can be avoided by careful construction and inspection, especially with respect to joints, and by use of sufficiently conservative radii and manhole spacings.

Pipe and Jointing Materials

The data collected from the canvassed cities show clearly that maintenance problems arising from poor joints are intensified by curves. More specifically, bucketing or scraping costs more in curved lines and also the chances of damaging the pipe material are increased. The principal source of trouble has been accumulations at joints subject to root penetration. Fins, especially from mortar joints, are also troublesome. For these reasons it is concluded that when curved sewers are used particular care must be taken to avoid both root penetration, fins, and other manifestations of poor joints. It is especially important to select a jointing method whose integrity is not affected by the pulling of

the joint to obtained the desired curvature.

For vitrified clay pipe the maximum joint deflection recommended by the pipe manufacturers is three degrees, which for all pipe sizes exceeds the actual deflections obtained if the minimum radius of curvature is established at 100 ft. The comparable amount of "pull" or separation at the joint ranges (for various pipe sizes and unit pipe lengths) from 0.2 to 0.7 in. The only sewerage agency which has made a study of pull amounts as related to curved sewers is the City of Los Angeles, which limits the maximum pull to 1 in. or to the amount matching a 100-ft radius of curvature.

Clay Pipe

With respect to jointing materials for clay pipe, in the opinion of many design engineers and maintenance officials concerned with sewer systems, further improvements in jointing procedures are desirable, primarily because of the persistent care and inspection which must be exercised to attain a good joint. Also, even when made with care, mortar joints may develop hair-line cracks which are subject to root penetration in varying degrees and hence such joints cannot be considered dependable in the vicinity of trees. Recognizing these deficiencies, the clay pipe industry has developed two new joints of the mechanical compression type whose integrity does not require such careful workmanship and inspection, viz., "plastisol" and "polyester" joints. Specifications applicable to both types have been developed by the ASTM as "Tentative Specification C425-58T," which include provisions for factory tests as well as hydrostatic acceptance tests for leakage. These specifications are believed to be equally applicable to curved as well as straight runs, provided that the shear loading test requirements be modified so that the test is carried out with the pipe joint first deflected in the maximum amount to be used on the job.

Asbestos-Cement and Concrete Pipe

Curvilinear alignments have been used for many years with asbestos-cement pipe, primarily for water lines, with excellent results. Little information is available, however, on the use of asbestos-cement pipe for curved sewers since only a few such installations have been made and these mostly in the past few years. There is every indication, however, that the ring-type coupling is excellently adapted to curvilinear sewer alignments.

Mortar joints are generally utilized with concrete sewer pipe, but a variety of rubber-gasketed (mechanical compression) joints are also available. These rubber-gasketed joints are not standardized, i.e., different manufacturers feature different joints, and the choice of joint should be limited to types proven by experience to be dependable.

Hydraulic Design Practice

Design standards used throughout the country were found to be fairly uniform for straight sewers, but little special attention has been given to curves. Most cities made no distinction in hydraulic criteria for straight and curved sewers, and minimum radius and other restrictions on curve dimensions were adopted arbitrarily.

The consensus was that design criteria for small sewers are approximations at best, that the presumed increased head loss due to curvature would be very small, and that there are already so many capacity safety factors incorporated in conventional design standards that any further allowance for curvature would be an unnecessary refinement. No different velocity or slope requirements were reported for curves, but several design

TABLE IX.—Summary of Minimum Radius Specifications (by Percentages)

Area	Minimum Radius (ft)					Avg Radius (ft)
	25–74	75–124	125–174	175–274	275 or More	
Southern California	0	40	0	50	10	185
Northern California	22	22	12	22	22	200
Oregon and Washington	0	100	100	0	0	100
Other states	29	29	29	13	0	118

engineers indicated that they preferred to have fairly steep slopes when using curves.

In order to obtain a dependable comparison of the relative head loss characteristics of curved vs. straight runs, controlled field experiments would have to be made. A theoretical comparison was attempted, however, based on estimating the savings in head losses in curved runs (due to elimination of angle points and to shortening of total length) versus the increases (due to the curvature along the pipe and to increased joint friction). This analysis, although not conclusive, indicated there is probably little difference in the hydraulic capacity of straight versus curved runs.

Manhole Spacing

Only eight communities recommended shorter spacings on curves than on straight sewer runs. For this group the curve spacings ranged from 62 to 89 per cent of the straight-run spacings.

Minimum Radius

Of the 66 reporting communities, 44 per cent had some minimum recommended curve radius, 6 per cent had a maximum joint deflection instead, and 21 per cent positively indicated that they had no expressed minimum radius. The distribution of minimum radii by percentages of communities is given in Table IX. The most common minimum prescribed radius was 100 ft. This value, although arbitrarily adopted by such cities as Los Angeles when initiating the use of curves, has been generally confirmed by experience as a realistic limitation in that few troubles have developed with curves of 100-ft or greater radii and there are relatively few instances where curves of sharper radii would be applicable.

Attitudes and Trends

The attitudes toward curved sewers reported were in most cases those of the city engineers, or in some cases, of the consulting engineers who were setting the design criteria of the community. They were tabulated as varying degrees of enthusiasm, as follows:

1. Curves are necessary to local sewerage practice.
2. Curves and straight lines are to be considered equal.
3. Curves should be used when indicated by economy.
4. Curves should be used sparingly.
5. Curves should be avoided if possible.
6. Curves are to be prohibited.

Table X gives the distribution of community attitudes by regions. Table X shows that a large majority of the communities which have used curves are still willing to install them under some conditions, and that at least 50 per cent will use curves whenever they are economically justified.

A total of seven communities prohibited the use of curves after having installed them for some period. In all seven the curves had been laid at

least 40 years ago. Five were having maintenance problems, mostly due to root intrusion through poor joints, and two were having difficulty locating wyes in the sewer. The remaining city prohibited curves because the particular rubber ring joints which had been used did not remain satisfactory under deflection.

Summary and Conclusions

Although curved sewers have been used with satisfaction at a number of cities since the turn of the century, the preponderance of use has been subsequent to World War II and has been closely related to the utilization of curved streets. Although employed in only a fraction of the total number of communities in the United States, curved sewers are well established and seem likely to be increasingly popular throughout the nation, particularly in view of the increasing trend toward use of curved streets in new subdivisions (in flat as well as hilly terrains). In the entire survey, of all the communities which have initiated utilization of curved sewers since World War II, only a few have indicated dissatisfaction and in these instances the dissatisfaction stemmed not from the curves per se but from faulty construction or inadequate records.

TABLE X.—Summary of Community Attitudes Toward Use of Curved Sewers (by Percentages)

Area	Attitude Toward Curved Sewers		
	Curves to be Used When Indicated	Curves to be Used Sparingly or Avoided	Curves to be Prohibited
Southern California	50	32	5
Northern California	57	19	19
Oregon and Washington	45	45	10
Other states	93	0	7

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APPENDIX

The following is a listing and explanation of symbols and conventions used in Tables I, II, and III.

Column	Symbol	Explanation
2	e	Estimated
3		One number indicates all curves were installed in that year
4	NS	New subdivisions
	H	Hills
	R	Residential area
	All	All over community
	D	In locations difficult to sewer with straight lines
	OT	Old part of town
5	M	Save manholes
	U	Avoid utilities
	E	Reduce excavation
	IR	Keep sewer in roadway
	CL	Permit curved property lines
	‖RW	Permit alignment along railroad or other right-of-way
	OR	Keep sewer out of roadway
	PA	Maintain parallel alignment
	OB	Avoid obstacles
	H	Improve hydraulic characteristics
6	VC	Vitrified clay
	C	Concrete
	T	Cement-asbestos
7	C	Cement mortar
	HP	Hot-pour (unspecified)
	RR	Rubber gasket or ring of unspecified manufacture

Column	Symbol	Explanation
	BR	Brant ring
	TR	Rubber ring for cement-asbestos pipe
9	—	Above line, range
10	—	Below line, average
11	—	Only one figure, without line, indicates only one value reported
12	NO	None in community
	R	Reverse curves
	V	Vertical curves
	HV	Combined horizontal and vertical curvature
	P	Prohibited in community
	C	Compound curves (changing radius)
13	℄	Street centerline
	‖℄	Parallel to street centerline
	All	Anywhere in street
	Sh	Shoulder of roadway
	Sdk	Under sidewalk
	RL	Rear of lots
	Pk	Parking strip
	Gtr	Under street gutter
	Eas	In easements
14	Y	Wye left in sewer
	St	House connection stub left from sewer to property line
	Tp	Tapping sewer
15	MM	Measurements from manholes
	MPL	Measurements from property lines
	Rec	Unspecified location records
	WT	Tag at surface wired to mouth of stub or wye
	Map	Unspecified measurements made by referring to sewer map
	Mk	Mark on curb or stake
	OS	System of offsets
	Sur	Surveying
	Inst	Instrument to locate wyes
16	Ex	Exfiltration test
	B	Passing ball through line
	Gl	"Glassing" the line
	Fl	Flushing and observing flow through manholes
	Inf	Infiltration test
	Insp	Inspection during construction only
17	=	Equal for straight and curved sewers
18	+	Additional cost on curves
19	less	Less cost on curves
20		No horizontal line indicates value applies to both straight and curved sewers
21		Minimum slope (in per cent) for 8-in. sewers given in some cases
22	S	Normal slope through manhole
23		No horizontal line indicates value applies to both straight and curved sewers
26	Pr	Preventive program
	St	Stoppage program
	Fl	Periodic flushing
	Ins	Regular inspection for incipient stoppages
27	=	Equal work and difficulties on both straight and curved sewers
28	+	Additional work required on curves (example: +2× means 200 per cent extra work required on curves)
29	NU	Not used
	RU	Rarely used
	NUC	Not used on curves
30	H	Hilly
	F	Flat
31	+	Root problems present in community
	N	No root problems
32	H	Heavy usage
	L	Light use in community
34		Dollars per year per mile of sewer under maintenance, or number of maintenance employees per mile of sewer
35	=	Equal work and cost on curves and straight sewers
	+	Additional work on curves
36	N	No problems
37	+	Additional difficulties on curves
	NE	No experience on curves
38	Nec	Curves necessary
	=	Curves equivalent to straight lines in all ways; to be used when indicated
	Ec	Curves to be used when economies will result
	Av	Curves to be avoided whenever possible
	P	Curves prohibited
	Sp	Curves to be used sparingly
39	=	Curves will continue to be used as at present
	+	Use of curves will increase (+CS in curved streets)
	Less	Fewer curves will be used in the future
	P	Curves are now prohibited
	Disc	Use of curves has been discontinued

IF YOUR 1960 DUES ARE UNPAID SEE PAGE 51

EFFECTS OF DETERGENTS ON OXYGEN TRANSFER IN BUBBLE AERATION

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In the first paper of this series (1), a report was given on the adverse effect of a number of retail synthetic detergents on oxygen transfer in bubble aeration. The preliminary studies were all conducted in Cambridge, Mass., tap water at concentrations of 50 mg/l of each of the syndets, as packaged for the retail trade. Rather wide variations were found in the degree to which the various retail products affected oxygen transfer.

Retail syndets are not homogeneous materials, but are mixtures of one or more surface active agents (often called "surfactants"), neutral salts, various "builders," which are frequently added to assist or augment the action of the surfactants, and miscellaneous impurities and by-products of their manufacture. The preliminary studies (1) led to the conclusion that in order to be fruitful, further research on syndets in relation to oxygen transfer should be conducted on their constituent materials, rather than on packaged retail products. The research reported in this paper was conducted primarily on a number of surfactants, some of commercial grade and some more highly refined, added to waters of several different types, in order to evaluate the effect of the chemical structure of the surfactant and the modifying effects, if any, of inorganic salts present in the water—all in relation to oxygen transfer.

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Fundamental Considerations

Intermolecular Attraction

A basic property of liquid surfaces is their tendency to contract to the smallest possible area. This property is attributed to strong inter-attractive forces between the molecules of the liquid itself and to the unbalanced nature of these forces at interfaces; liquid molecules at a surface can be attracted to other liquid molecules only in an inward direction or in one parallel to the surface, but not outward from the main body of the liquid. The spontaneous contraction of a liquid surface demonstrates that there is free energy associated with it, that is, work must be done on it to extend or increase the surface area. The common unit in which surface tension is measured, dynes/cm, is numerically equal to work (ergs or dyne-cm) per unit area (sq cm) and is therefore equivalent to the surface free energy.

When certain solutes are introduced into a liquid like water, the intermolecular attraction among the solvent (water) molecules themselves may be stronger than that between the molecules of the solvent and those of the solute, the result of which is to cause the surface of the liquid to be relatively richer in solute molecules than the main body of the liquid. Those solute materials which exhibit this adsorption phenomenon are known as surface active agents. Because water containing such surfactants is more strongly attracted unto itself than to them, it is not surprising that the

surface free energy (surface tension) of such mixtures is lower than that of pure water. As long ago as 1878, Gibbs expressed the relationship between the amount of adsorbed solute and the change in surface tension in the equation which bears his name.

A change in surface tension is not the only effect noted at the interfaces of solutions of surfactants. It has been shown that the viscosity of adsorbed monolayers of surface active materials is markedly higher than that of the solvent (2)(3). Harkins (3), in particular, has demonstrated remarkable increases in the surface viscosity of aqueous solutions of the normal fatty acids and the normal fatty alcohols containing from 14 to 18 carbon atoms. For the alcohols, extremely rapid increases in surface viscosity were noted with decrease in surface tension whenever the latter exceeded as little as 5 to 10 dynes/cm below the normal value for water.

Adsorption phenomena at the surface of water containing surface active agents are not limited to those caused by a monolayer of the surfactant. In the case of ionic surfactants, it is necessary that a double layer of surfactant ions and ions of the opposite charge occur close to the surface in order to preserve the electro-chemical neutrality of the solution. The gegenions, or ions of opposite charge, may be the inorganic ion accompanying the surface active fraction of the surfactant originally added, or may be gegenions from other inorganic salts in solution. Recently, by the use of radiotracer techniques, Dixon *et al.* (4) not only have verified the theoretical necessity for a double layer but have shown that the primary double layer apparently induces secondary layers. Multilayer adsorption may thus be anticipated whenever a surfactant is present in a water containing other solutes, particularly inorganic ones. Of interest, too, is their finding that such adsorbed multilayers are not limited in their occurrence to ionic surfactants but are to be found with nonionic ones as well.

Oxygen Transfer

The effect, on oxygen transfer, of the presence or absence of surfactants and other substances in the water in an aeration device or system may be expressed in terms of a gross coefficient of oxygen transfer for the particular system. The relationship between the rate of oxygen transfer, the deficiency of dissolved oxygen which is the fundamental driving force causing the oxygen to be dissolved, and the coefficient, k_2, is expressed.

$$\frac{dC_t}{dt} = 2.3\, k_2\, D = 2.3\, k_2 (S - C_t) \ldots (1)$$

in which

$\frac{dC_t}{dt}$ = the rate of oxygen transfer, mg/l/min;

C_t = dissolved oxygen concentration in the water at any time t, mg/l;

t = time, min;

S = dissolved oxygen concentration in the water at saturation, mg/l;

$D = S - C_t$ = dissolved oxygen deficiency at any time t, mg/l; and

k_2 = gross coefficient of oxygen transfer for the system, 1/min.

The basic principles of the absorption of gases into liquids, especially the two-film theory of Whitman (5) and Lewis and Whitman (6), have recently been reviewed and restated by Haney (7). Comparisons reveal that Haney's k_A equals 60 times k_2, above, because his time units are expressed in hours rather than in minutes, and that both these coefficients are related to the fundamental two-film theory, as applied to the solution of a slightly

soluble gas, like oxygen, as follows:

$$k_2 = \frac{k_A}{60} = \frac{k_L\,(10^{-6})\,A}{2.3\,(60)\,V} \quad \ldots . (2)$$

in which

k_L = the transfer coefficient through the liquid film, g/(hr) (sq cm) (g/ml);

A = total area of the liquid-gas interface, sq cm; and

V = volume of water, ml.

From Equation 2 it may be seen that for a series of experiments in an apparatus in which the volume of water is always the same, the gross coefficient of oxygen transfer, k_2, is proportional to the product of the transfer coefficient per unit area, k_L, and the total interfacial area, A. In an oxygen transfer process in which oxygen is supplied by means of bubbles of air, the introduction of an agent which lowers the surface tension of the water would be expected to increase the total area of contact between the gas and the liquid because of the decreased bubble size and increased number of bubbles resulting when air is supplied at the same volumetric rate. In other words, reduction of the surface-free energy of the liquid makes possible a greater area when the same amount of work is done thereon, in this case by compressed air. If the total interfacial area of a water-surfactant system may be expected to increase, the gross coefficient of oxygen transfer, k_2, would also increase unless there were a corresponding or greater decrease in the value of the unit transfer coefficient, k_L. While k_2 may be evaluated fairly readily in an experimental apparatus using bubble aeration, the difficulty of determining A renders the calculation of k_L equally difficult and was not attempted in these studies. Nevertheless, the proportionality between the product, k_LA, and k_2 may provide important qualitative insight in the interpretation of results expressed quantitatively in terms of k_2 only.

Experimental Method

The aeration apparatus used in these investigations was the same as used in the preliminary studies (1), but certain improvements were made in the devices controlling and measuring the flow of air to the diffuser so that it was possible to control the aeration rate more closely (within about 3.5 per cent). In all of the investigations reported herein, air was supplied at a rate of 110 mg/min (91 ml of free air per min), which is approximately the same rate as that used in the preliminary studies. As a precaution against the contamination of the water by residual surfactant from a previous run adhering to the diffuser, the technique of Holroyd and Parker (8) of cleaning the diffuser with a slurry of bentonite clay was used between successive runs. Several test runs verified its effectiveness.

Surface tension was determined in these studies by the Ring Method, using a DuNoüy Tensiometer. A 100-mm crystallizing dish was used to contain the 50-ml samples on the platform of the Tensiometer. All samples were aged 35 to 40 min before operating the Tensiometer, since the surface tension of surfactant solutions is known to decrease with time, rapidly at first, and then more slowly, under quiescent conditions. The aging period selected was one which a series of preliminary experiments showed would yield consistent results and beyond which further aging would cause little additional decrease in surface tension.

In these studies, the gross coefficient of oxygen transfer, k_2, was computed by means of the "slope method" of Thomas (9)(10), using an electronic calculator. Among the advantages of using the slope method were (*a*) the elimination of the dissolved oxygen concentration at saturation as a factor in the calculation of k_2, and (*b*) co-

incidental determination of the standard error of each value of k_2.

Experimental Results

For the investigations reported herein, it was decided to use a concentration of surface active agent comparable to that which would be found on the addition of 50 mg/l of retail synthetic detergent to water. Inasmuch as typical retail syndets contain about 30 per cent surface active agent (11)(12), a uniform concentration of 15 mg/l was used throughout the studies when adding the various surfactants to different waters. Whenever "builders" or other constituents of retail syndets were added in addition to the surface active agents, they were added in approximately the same proportion to the surfactant as might be found in a typical syndet.

Bogan and Sawyer's classification (13) of the major types of anionic and nonionic surfactants used in producing commercial syndets was used as a guide in the selection of appropriate material with which to work in these studies. No cationics were studied because of their small usage and the fact that they would be precipitated by the anionics in most situations of interest to sanitary engineers. Investigations reported herein were conducted in, and may be classified in, essentially two phases:

1. Surface active agents of commercial grade, representing each major group in Bogan and Sawyer's classification or representing related chemical structures, or both, were studied in two tap waters of rather different composition. Commercial surface active agents are, unfortunately, mixtures of homologs, isomers, and by-products of their manufacture and so can be considered only to approximate the average chemical composition stated for them.

2. Three homologous series of alkyl benzene sulfonates which were either pure chemical identities or much more highly refined products than normal commercial materials were studied in several synthetic waters.

Major Surfactant Types of Commercial Grade

Bogan and Sawyer (14)(15) used the same materials as were used in this phase of the investigation in their work on chemical structure and biochemical oxidation. Narrow distillation cuts from two commercial alkyl benzene sulfonates were supplied by Procter and Gamble and served to represent the major cyclic anionic surfactants. One of these was a keryl benzene sulfonate, i.e., the alkyl group was derived from kerosene and constituted mostly straight-chain materials; the other, a polypropylene benzene sulfonate, had a highly branched alkyl chain, but, like the keryl benzene sulfonate, the alkyl group contained an average of 12 carbon atoms. Three representatives of the acyclic anionics were used. One of these, also supplied by Procter and Gamble, was *n*-dodecyl sulfate and was the only pure chemical identity utilized in this phase of the studies. Commercial Igepon AP-78 was utilized to represent the sulfonated fatty-ester types; it is probably mostly the oleic-acid ester of sodium isethionate. Surfactants of the sulfonated fatty-amide type were represented by commercial Igepon T-77, which is a commercial grade of sodium N-methyl-N-oleoyl taurate. The Igepons are products of General Dyestuff Corporation.

Among the nonionics, an alkyl phenoxy polyethyleneoxide was chosen to represent the cyclic type; Rohm and Haas' OPE-5, in which the alkyl group is a highly branched one containing eight carbon atoms and in which the ethoxy group averages five moles of ethyleneoxide, was used. Of the acyclic nonionics, commercial Ethofat 60/15 and Ethofat 60/60 were used to represent the polyethyleneoxide fatty esters; the fatty-acid groups of both are

TABLE I.—Aeration Data for Certain Anionic Surfactants at 25°C

Surfactant (15 mg/l)	Boston Tap Water			Cambridge Tap Water		
	Surface Tension (dynes/cm)	Transfer Coefficient $k_2(10^6)$ (1/min)	Foam Height (in.)	Surface Tension (dynes/cm)	Transfer Coefficient $k_2(10^6)$ (1/min)	Foam Height (in.)
None; water only	71.5	297±8	0	71.7	313±10	0
Keryl benzene sulfonate	50.8	267±6	46	42.3	196±6	45
Polypropylene benzene sulfonate	53.3	290±10	27	50.8	228±4	42
n-dodecyl sulfate	67.6	225±7	0	61.8	204±7	0
Sulfonated fatty ester	29.2	207±5	38	29.6	141±9	36
Sulfonated fatty amide	31.3	180±6	47	31.7	194±7	47

stearates, but the former contains only 5 moles (penta) of ethyleneoxide while the latter contains 50 moles (pentaconta). Surfactants of the polyethyleneoxide fatty amide type were represented by Ethomid HT/15 and Ethomid HT/60, the fatty groups of both of which are derived from hydrogenated tallow; Ethomid HT/15 contains 5 moles of ethylene oxide whereas Ethomid HT/60 contains 50 moles. The Ethofats and the Ethomids are products of Armour and Company.

Aeration Data

Each of the foregoing surfactants was subjected to aeration runs in both Boston, Mass., tap water and in Cambridge, Mass., tap water. The results of these runs are shown graphically in Figure 1, in which the aeration data have been plotted in terms of the per cent deficiency of saturation of dissolved oxygen, where the saturation value in each case was that computed by Thomas' slope method. For an equation representing a first-order reaction, such as involved in oxygen transfer, the slope of such plots represents the coefficient of the equation, k_2 in this case. The more nearly vertical the lines, the higher the value of k_2, and the more nearly horizontal, the lower the value of k_2. Table I shows additional aeration data for the anionic surfactants and Table II shows similar data for the nonionic surfactants. While all the aeration runs were made at approximately 25°C, the transfer coefficients k_2 have been corrected to 25°C in those cases where the temperature differed from that. Also shown in the columns for the transfer coefficients are the "standard errors" for each coefficient, as calculated from Thomas' slope method.

In Tables I and II, the column headed "Foam Height" represents the total accumulation of foam or froth

TABLE II.—Aeration Data for Certain Nonionic Surfactants at 25°C

Surfactant (15 mg/l)	Boston Tap Water			Cambridge Tap Water		
	Surface Tension (dynes/cm)	Transfer Coefficient $k_2(10^6)$ (1/min)	Foam Height (in.)	Surface Tension (dynes/cm)	Transfer Coefficient $k_2(10^6)$ (1/min)	Foam Height (in.)
None; water only	71.5	297±8	0	71.7	313±10	0
Alkyl phenoxy polyethoxy	51.4	139±5	2	40.5	151±7	5
Pentaethoxy fatty ester	39.2	197±3	48	41.4	218±8	27
Pentacontaethoxy fatty ester	49.1	170±7	2	50.1	144±11	½
Pentaethoxy fatty amide	40.5	124±4	4	39.5	134±4	24
Pentacontaethoxy fatty amide	51.2	161±12	1	50.6	233±15	1

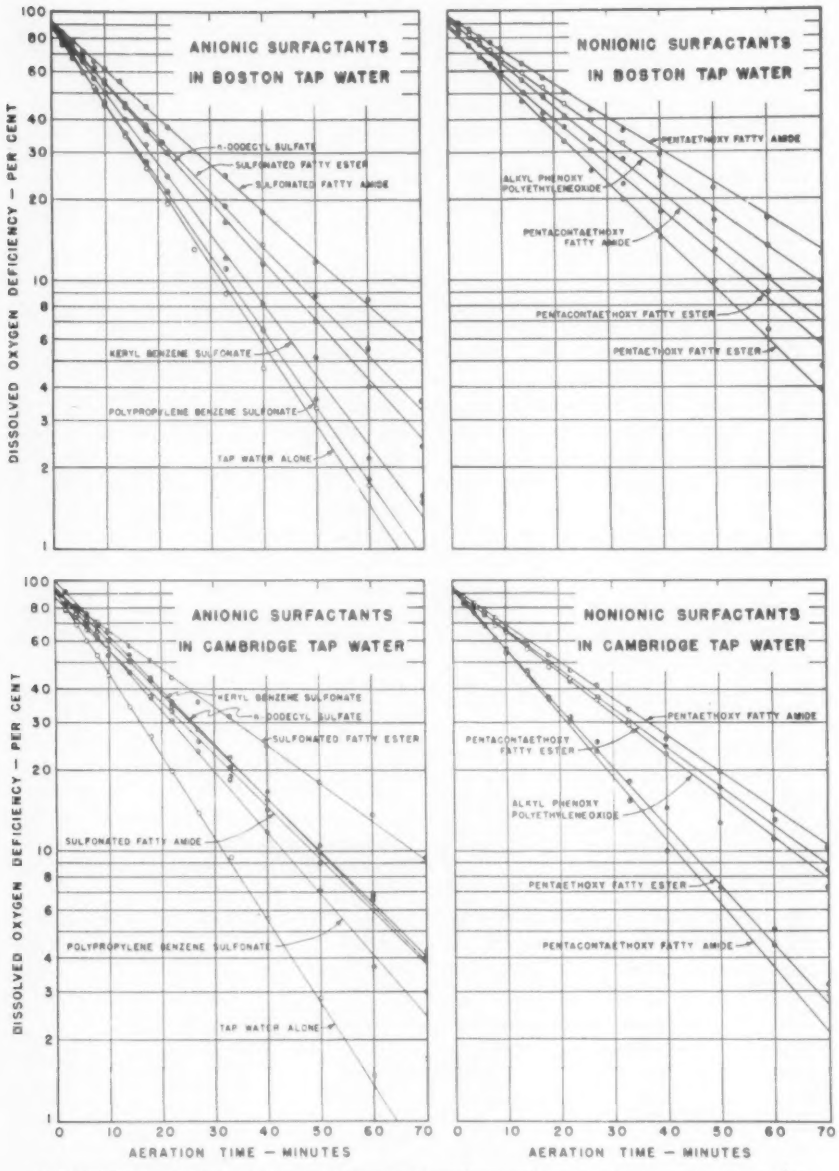

FIGURE 1.—Effect of 15 mg/l of several surface active agents on oxygen transfer in two tap waters.

in the aeration column at the termination of each run of 100-min duration. They are presented as a matter of interest to show the great variation in degree of frothing experienced with the various surfactants and, in some cases, with the same surfactant in different waters.

Evaluation of Data

The significant differences noted, in several cases, between the k_2 values in Boston and Cambridge water, for the same surfactant, lead to the speculation that either the pH or the mineral content of the water had some significant bearing on the results. Boston tap water is a very soft water and has a relatively low pH (total solids, 30 to 40 mg/l; hardness, 15 to 20 mg/l; alkalinity, 10 to 15 mg/l; and pH, 6.5 to 7.6). Cambridge tap water is a harder water than Boston water and has a somewhat higher pH (total solids, 110 to 125 mg/l; hardness, 65 to 80 mg/l; alkalinity, 30 to 35 mg/l; and pH, 7.2 to 8.5). To determine whether pH of itself had any drastic effect on the k_2 value, a synthetic water of 50 mg/l hardness and 33 mg/l alkalinity was prepared. Aeration runs on this water, with and without keryl benzene sulfonate, were made at its normal pH of about 8.1, at a pH of about 5.3 achieved by the addition of carbon dioxide, and at a pH of about 5.3 achieved by the addition of KH_2PO_4. In the absence of the surfactant, no significant differences in the value of k_2 were found. In the presence of the surfactant, no significant differences at the various pH's were found, although in all runs with the surfactant present the k_2 value was significantly lower than in its absence and was approximately the same as that noted in Cambridge tap water.

At the conclusion of this phase of the investigation, it appeared that the effect of surface active agents on oxygen transfer in water during bubble aeration might be ascribed to one or more of the following factors: (*a*) the size, type, and attachment of the alkyl group of the surfactant; (*b*) the nature of the intermediate group linking the hydrophobic alkyl group to the hydrophilic portion (sulfonate, sulfate, or ethoxy group) of the surfactant molecule; (*c*) type and size of the hydrophilic group; (*d*) mineral salts dissolved in the water; and (*e*), possibly, builders present in retail syndets. In the second phase of this investigation, it was decided to investigate several of these factors through the use of the refined alkyl benzene sulfonates.

Refined Alkyl Benzene Sulfonates

Investigation of the effect of chemical structure in relation to oxygen transfer was centered on three homologous series of alkyl benzene sulfonates supplied by the Continental Oil Company. The first series consisted of the straight-chain alkyl benzene sulfonates containing 8, 10, 12, and 14 carbon atoms in the alkyl group and having normal attachment to the benzene ring. The second series consisted of straight-chain alkyl benzene sulfonates containing 8, 10, and 14 carbon atoms, but with attachment to the benzene ring occurring at the second carbon atom in each instance. The alkyl benzenes from which these seven materials were prepared were chemically pure, and after they had been sulfonated and neutralized, infrared examination revealed the finished products to be almost exclusively *para* isomers, according to the supplier. The third series consisted of four polypropylene benzene sulfonates whose alkyl groups were primarily di-, tri-, tetra-, and pentapropylene, respectively. These four materials were prepared from very narrow distillation cuts of propylene polymers and, therefore, were not chemically pure but included some isomers and homologs other than the principal ones indicated by the nomenclature.

Synthetic Waters

In view of the apparent importance of mineral salts in the water in affecting oxygen transfer in the presence of surface active agents, it was decided to abandon the use of tap waters in this phase of the studies and to use instead synthetic waters prepared

from distilled water and appropriate amounts of salts. Four different types of water were used, as follows:

1. Distilled water was used to ascertain the effect of these surfactants in the absence of any minerals found in natural water.

2. A water synthesized to contain 50 mg/l of hardness was used to represent waters of moderate hardness; the water reported herein contained 33 mg/l of hardness, added as calcium sulfate, 17 mg/l of hardness, added as magnesium sulfate, and 33 mg/l of alkalinity, added as sodium bicarbonate, the whole having a pH of about 8.1. Water of similar hardness, in which the hardness ions were added as the chloride salts rather than the sulfates, was also used in connection with tests on all members of the first two series of alkyl benzene sulfonates but with little or no significant difference in results between the sulfate and chloride type of hardness, hence only the results of the former are included herein.

3. A synthetic water was used containing salts of the quantity equivalent to that of the water of 50 mg/l hardness, but in this case sodium sulfate was added instead of calcium and magnesium sulfate, the resulting pH being about 8.3. A comparable water in which sodium chloride replaced the sodium sulfate also was used in aeration runs for all members of the first two series, and again little or no significant differences were found between the sulfate and chloride types, hence only the former are tabulated herein.

4. A synthetic water of high hardness, 300 mg/l, also was used, containing 200 mg/l added as calcium sulfate and 100 mg/l added as magnesium sulfate; 200 mg/l of alkalinity, added as sodium bicarbonate, also was present, and the pH of the water was about 8.3.

In addition to runs on all of these waters, additional salts and builders were added to certain of these waters to provide additional information, as will be explained later.

Results from Normal ABS

Results of runs on the normal straight-chain alkyl benzene sulfonates in the four major types of waters are shown in Table III. In this table only the computed values of k_2, including their standard errors, and the surface tension data are shown. Frothing data are not shown because it is not germane to this discussion, but as a matter of fact very little frothing was observed with the normal straight-chain materials; in fact, for *n*-tetradecyl benzene sulfonate, especially, and to a lesser extent for *n*-dodecyl benzene sulfonate, a marked tendency toward precipitation of the surfactant was noted in all cases where

TABLE III.—Oxygen Transfer Coefficients k_2 and Surface Tension in the Presence of 15 mg/l of Normal Straight-Chain Alkyl Benzene Sulfonates in Waters of Several Compositions

Alkyl Group of Surfactant	Distilled Water		Water Containing Sodium Salts Only		Water Containing 50 mg/l Hardness		Water Containing 300 mg/l Hardness	
	$k_2(10^4)$ (1/min)	Surf. Tens. (dynes/cm)	$k_2(10^4)$ (1/min)	Surf. Tens. (dynes/cm)	$k_2(10^4)$ (1/min)	Surf. Tens. (dynes/cm)	$k_2(10^4)$ (1/min)	Surf. Tens. (dynes/cm)
None; water only	327±10	70.5	—	—	327±11	71.5	318±5	71.8
n-octyl	499±11	70.4	347±17	71.2	257±8	70.4	226±7	69.7
n-decyl	243±11	70.7	217±5	70.0	203±8	57.0	211±4	55.8
n-dodecyl	215±10	60.2	239±4	56.3	201±4	63.5	218±7	62.6
n-tetradecyl	178±9	58.9	166±6	58.8	318±7	71.3	307±12	71.4

TABLE IV.—Oxygen Transfer Coefficients k_2 and Surface Tension in the Presence of 15 mg/l of Straight-Chain Alkyl Benzene Sulfonates with Secondary Attachment in Waters of Several Compositions

Alkyl Group of Surfactant	Distilled Water		Water Containing Sodium Salts Only		Water Containing 50 mg/l Hardness		Water Containing 300 mg/l Hardness	
	$k_2(10^4)$ (1/min)	Surf. Tens. (dynes/cm)	$k_2(10^4)$ (1/min)	Surf. Tens. (dynes/cm)	$k_2(10^4)$ (1/min)	Surf. Tens. (dynes/cm)	$k_2(10^4)$ (1/min)	Surf. Tens. (dynes/cm)
None; water only	327±10	70.5	—	—	327±11	71.5	318±5	71.8
1-methyl-heptyl	390±18	70.4	374±6	71.2	274±14	70.3	256±6	70.1
1-methyl-nonyl	295±17	70.2	276±5	70.0	249±4	60.3	220±10	50.4
1-methyl-tridecyl	183±7	39.3	209±4	40.1	177±6	44.2	183±3	44.8

hardness ions were present in the water, and the higher value of k_2 in the presence of these ions, as compared to their absence, is attributed to their apparent ability to destroy very largely the surface active properties of this longest member of the series, a fact borne out by the surface tension data as well. In Table III, the generally decreasing trend of k_2 with chain length may be noted, and, with the exception previously noted, a generally decreasing trend on the addition of mineral salts may also be noted. In the case of *n*-octyl benzene sulfonate, two of the four values of k_2 will be seen to exceed those for water in the absence of surfactant, a fact which clearly implies that the effect of this surfactant in decreasing bubble size and increasing the total aeration area greatly eclipses whatever effect it may have on the transfer coefficient for a unit area, k_L.

Results with Secondary ABS

In Table IV, the results of aeration experiments on the straight-chain alkyl benzene sulfonates with attachment at the second carbon atom are shown for the several waters used. In this case, also, the longest member of the series showed some tendency toward precipitation from solution in hard waters but not nearly to the extent that the normal compound of the same length had done, nor, apparently, to a degree sufficient to reverse the trend in the value of k_2. In each water, the trend of decreasing k_2 values with increasing length of the alkyl chain is readily seen in Table IV. The effect of the presence of mineral salts in the water is also fairly apparent, especially the adverse effect of the hardness-causing salts.

Results with Highly-Branched ABS

Because the polypropylene benzene sulfonates available contained various known amounts of residual sodium sulfate, it was decided to add appropriate amounts of sodium sulfate so as to bring its total up to 35 mg/l when 15 mg/l of these alkyl benzene sulfonates were added to the four waters and aerated. Thus, the data shown in Table V for the polypropylene benzene sulfonates in the four synthetic waters are more nearly comparable to that for a light-duty syndet, containing 30-per cent surfactant, at a concentration of 50 mg/l. Trends of generally decreasing values of k_2 with increasing length of the alkyl chain and with increasing mineral content of the water may be noted in Table V, too, but the trends are less sharply defined than for the straight-chain types. Of possible interest regarding the frothing characteristics of these surfactants is the observation that the dipropylene benzene sulfonate did not froth at all in any of these waters and the tripropylene did so only very slightly. The tetramer and pentamer,

TABLE V.—Oxygen Transfer Coefficients k_2 and Surface Tension in the Presence of 15 mg/l of Polypropylene Benzene Sulfonates (Plus 35 mg/l of Sodium Sulfate) in Waters of Several Compositions

Principal Polymer of Alkyl Group	Distilled Water		Water Containing Sodium Salts Only		Water Containing 50 mg/l Hardness		Water Containing 300 mg/l Hardness	
	$k_2(10^4)$ (1/min)	Surf. Tens. (dynes/cm)	$k_2(10^4)$ (1/min)	Surf. Tens. (dynes/cm)	$k_2(10^4)$ (1/min)	Surf. Tens. (dynes/cm)	$k_2(10^4)$ (1/min)	Surf.Tens. (dynes/cm)
None; water only	327±10	70.5	—	—	327±11	71.5	318±5	71.8
Dipropylene	348±4	71.1	335±8	71.2	305±12	70.6	285±5	71.1
Tripropylene	258±10	70.5	221±4	70.5	224±10	68.5	196±6	64.5
Tetrapropylene	226±6	61.8	211±4	58.1	231±4	53.7	186±10	49.5
Pentapropylene	183±3	34.6	208±11	32.6	196±6	28.3	163±7	28.6

however, both frothed profusely in all waters and to about the same degree, nearly four feet of foam being accumulated by the end of the 100-min runs.

Results with Tripolyphosphate Added

Inasmuch as the mineral salts in water appeared to have marked effect on oxygen transfer in the presence of surfactants, a series of runs involving one of the important inorganic builders used in the formulation of syndets also was made. These runs were made in the synthetic water of 50 mg/l hardness with 20 mg/l of sodium tripolyphosphate builder, as well as 15 mg/l of sodium sulfate, added together with the usual 15 mg/l of each of the 11 alkyl benzene sulfonates. A series of preliminary runs on the straight-chain types, in which 35 mg/l of sodium sulfate was added in addition to the surfactant, established that in the water of 50 mg/l hardness there was little or no significant difference between the results with the 35 mg/l of sodium sulfate present as compared to the earlier results in its absence. The results of the runs in which sodium tripolyphosphate was added are shown in Table VI. For both series of straight-chain types, with the possible exception of the 1-methyl-nonyl benzene sulfonate, no significant differences will be noted between the results of Table VI and the results for the 50 mg/l hardness water shown in Tables III and IV. In the case of the polypropylene benzene sulfonates, however, significantly lower values for k_2 may be seen in the presence of this builder as opposed to its absence (Table V).

Discussion

The generally adverse effect of the presence of surface active agents on oxygen transfer in bubble aeration has been noted by other observers. Holroyd and Parker (8), using apparatus somewhat similar to that of the authors, added various amounts of two British syndets to plain water and observed drastic reductions in the rate of solution of oxygen in the presence of these syndets, as compared to their absence. In a study of even greater significance to sanitary engineers, Degens *et al.* (16) added 15 mg/l of tetrapropylene benzene sulfonate to one of two identical pilot plants treating sewage by the activated sludge process and found it necessary to triple the rate of application of air to the unit containing the surfactant in order to achieve performance comparable to that of the control; the additional air required cannot be accounted for by the BOD of the surfactant since they, like Bogan and Sawyer (14), found this material to be utilized only very slowly in this biological system. The information contained herein concerning the various

factors which influence the effect of surfactants and syndets on oxygen transfer is offered to strengthen the information already available.

Size, Type, and Configuration of Surfactant Molecule

The three series of alkyl benzene sulfonates provide information which show the importance of the size, type, and attachment of the alkyl group to the rest of the surfactant molecule in materials of this type. In Figures 2 to 5 the gross coefficient of oxygen transfer has been plotted against the number of carbon atoms in the alkyl group of each of these three series for four different conditions in the water. In Figure 2 it may be seen quite clearly that the transfer coefficient decreases with increasing length of the alkyl chain for all three series. In addition, deviation from the normal straight-chain type toward secondary attachment and greater branching tends to flatten the curves, that is, it tends to lessen the differences between adjacent members of the series. Rather similar trends will be noted in Figures 3, 4, and 5, except for the reversal previously noted for the normal straight-chain type and attributed to the insolubility of the calcium and magnesium salts of the higher members of this series. The tabular data show that surface tension in the presence of these surfactants follows the same trends, that is, generally downward with increasing chain length, with the exception of the higher members of the normal straight-chain alkyl benzene sulfonates. Increased surface activity or surface adsorption, as measured by the surface tension criterion, thus was accompanied by increased resistance to oxygen transfer.

Examination of the data in Tables I and II, particularly the latter, shows that the hydrophobic or alkyl group is not the only factor of importance in determining the effect of various surfactants on oxygen transfer. For example, the length of the hydrophilic ethylene-oxide group in the nonionic fatty esters appears important in affecting oxygen transfer, lower values of k_2 being associated with the fatty ester having the larger ethoxy group. In the case of the nonionic fatty amides, however, the larger ethoxy group was associated with larger values of k_2, indicating, perhaps, that not

TABLE VI.—Oxygen Transfer Coefficients $k_2(10^4)$ in the Presence of 20 mg/l of Sodium Tripolyphosphate Builder (Plus 15 mg/l of Sodium Sulfate) in Combination with 15 mg/l of Various Alkyl Benzene Sulfonates in a Water of 50 mg/l Hardness

No. of Carbon Atoms in Alkyl Group	Type of Alkyl Group of Surfactant		
	Straight; Normal Attachment	Straight; Secondary Attachment	Propylene Polymer
6	—	—	267±7
8	240± 8	282±14	—
9	—	—	191±7
10	217± 4	224± 3	—
12	207±11	—	192±6
14	310±19	177± 6	—
15	—	—	183±5

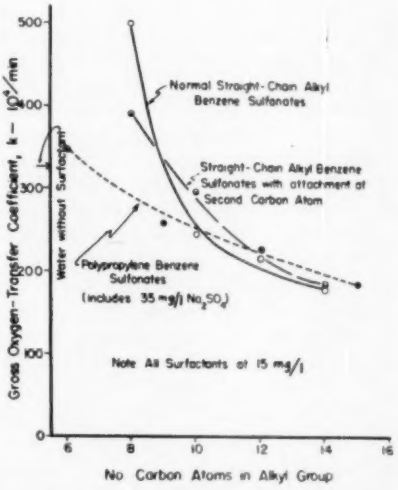

FIGURE 2.—Effect of size and nature of alkyl group on oxygen transfer in distilled water.

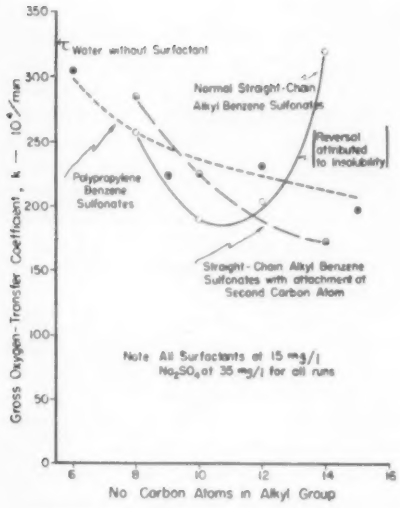

FIGURE 3.—Effect of size and nature of alkyl group on oxygen transfer in water of 50 mg/l hardness.

only is the total number of moles in the solubilizing group important, but also its manner of attachment to the hydrophobic portion, e.g., ester vs. amide. Comparison of the anionic ester in Table I to the nonionic ones in Table II and comparison of the anionic amide to the nonionic amides also appears to indicate that both the ionic nature and the chemical configuration of the hydrophilic group (sulfonate vs. ethoxy) is of importance.

That the type, size, and arrangement of both the hydrophobic and hydrophilic portions of surfactant molecules should affect the degree of their influence on oxygen transfer is, in general, in accordance with experience in utilizing them for the various purposes to which their surface activity is put to use, as, for example, in detergency and in wetting agents. The entire concept of surface activity hinges on the presence, in one molecule, of both hydrophobic and hydrophilic groups, and if the delicate hydrophobic-hydrophilic balance, as it is sometimes called, determines the suitability of surfactants for various purposes, it is not surprising that it is a key factor in the relative influence of various surfactants on oxygen transfer.

Effect of Salts and a Builder

Both the tabular data and Figures 2 to 5 indicate that when surface active agents are present, the addition of inorganic salts, and in some cases, the addition of the builder, sodium tripolyphosphate, has a further effect on oxygen transfer. (In comparing Figure 2 with Figures 3, 4, and 5, it should be noted that a smaller scale was used for the values of the oxygen-transfer coefficient in Figure 2 than in the other figures.) That the migration of ionic surfactants to an interface must be accompanied by gegenions probably accounts for the importance of these salts. The presence of added amounts of salts makes available sufficient gegenions to promote not only double-layer adsorption at the surface, but multilayer adsorption as well, as demonstrated by the experiments of

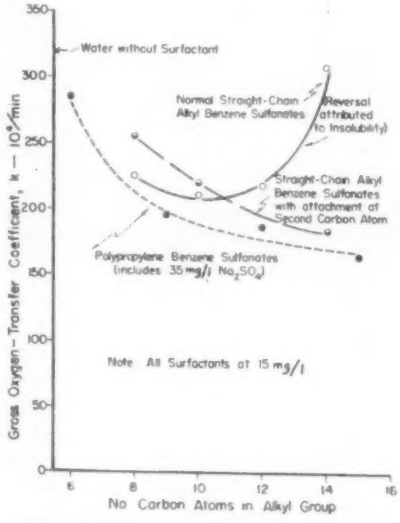

FIGURE 4.—Effect of size and nature of alkyl group on oxygen transfer in water of 300 mg/l hardness.

Dixon *et al.* (4). Multi-valent ions, such as the calcium and magnesium ions causing hardness in the water, would undoubtedly be more strongly adsorbed to the initial double-layer, much as they are in chemical coagulation, and would thus more strongly promote multilayer adsorption than would the univalent sodium ions. The behavior of the builder, sodium tripolyphosphate, in causing additional adverse effects in the presence of the polypropylene benzene sulfonates but not in the presence of the other types of alkyl benzene sulfonates appears rather hard to explain on the same basis, since its multi-valent portion is of the same charge as these anionic surfactants. However, Dixon *et al.* (4) demonstrated that the induced multilayers in the presence of surfactants include ions of both charges, regardless of the ionic charge of the surfactant and regardless of the source of those ions in the solution. Another possibility is that when the surfactant is of the polypropylene benzene sulfonate type, the initial gegenions, which are cationic, are so strongly adsorbed at the surface that the net charge of the initial double layer is reversed; in subsequent adsorption the anionic tripolyphosphate ions, as well as other anions in the water, would become gegenions.

The fact that surfactants are augmented in their effect on oxygen transfer by the presence of salts in the water, particularly calcium and magnesium salts, is in accordance with other situations in which their surface activity is important. Speaking of detergency, Van Antwerpen (17) states: "If present in low concentrations, the salts of hard water act as a builder for any detergent. As the hardness of the water increases, a point is usually reached at which precipitation begins." Not only the first part of this statement appears to be true regarding the influence of salts of hard water on oxygen transfer in the presence of surfactants, but the last part is also borne out by the effect of these salts in precipitating *n*-tetradecyl benzene sulfonate. Regarding the effect of mineral salts, it is of interest to note that Table II indicates that even the nonionic surfactants are not immune to the influence of water quality, as shown by the difference in Boston and Cambridge tap waters.

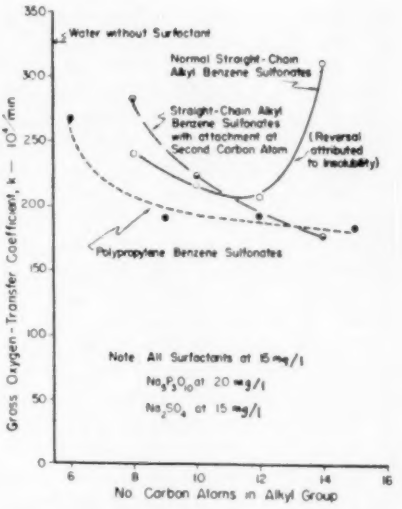

FIGURE 5.—Effect of size and nature of alkyl group on oxygen transfer in water of 50 mg/l hardness and containing sodium tripolyphosphate.

Gas Transfer Theory

Explanation of the influence on oxygen transfer of adsorbed double-layers or multilayers of surfactants and mineral salts at the bubble surface may be sought in their physicochemistry, in the two-film theory of gas transfer, and in the physical factors affecting gas transfer. The two-film theory of gas transfer visualizes a gas-liquid interface as comprising a film of essentially quiescent gas occurring on the gas-phase side of the interface and a similar film of quiescent liquid on the liquid-phase side. Transfer of gas through these thin films is considered

to take place only by the very slow process of molecular diffusion. The resistances of the two films are additive, but for a slightly soluble gas, like oxygen, the gas film is considered of little consequence and therefore the liquid film controls the rate of transfer to the main body of liquid. A simple explanation, then, of the effect of surfactants would be that any foreign molecules or aggregations of molecules which tend to increase the thickness of this liquid film will increase the path the gas must follow before it reaches the main body of the fluid and hence will reduce the rate at which gas can reach the main body of fluid. In connection with bubble aeration, the finding of McBain and Davies (18), and McBain and Swain (19) that the adsorption of surfactants at the surface of gas bubbles moving through solutions of surfactants is several times that predicted by Gibbs' equation is of considerable interest. The fact that the Gibbs equation, which is intended to apply only to quiescent conditions, is invalid under dynamic conditions of adsorption and tends to underestimate the amount of adsorption under these conditions may explain why Holroyd and Parker (8) found the syndets they tested to interfere greatly with oxygen transfer in bubble aeration but hardly at all under quiescent conditions.

Viscosity and Turbulence

Among the physical factors which are known to affect oxygen transfer are the viscosity of the liquid and the turbulence in the fluid, in this case in the vicinity of the rising air bubbles. Haslam *et al.* (20) have presented data to show that the unit transfer coefficient k_L is proportional to the 2/3 power of the reciprocal of kinematic viscosity. Other investigators also have shown that gas transfer rates decrease with increasing viscosity of the fluid. Earlier in this paper, reference was made to the high surface viscosity found by Harkins (3) in the presence of several surface active agents. If the viscosity of a homogeneous fluid plays an important role in gas transfer in the direction of reducing transfer as viscosity rises, it appears reasonable that a thin heterogeneous layer of high-viscosity material between the gas and the mass of fluid to which it is being transferred would also affect adversely the way in which gas would pass through that layer into the main liquid.

Another effect of surface viscosity may be to reduce the turbulence in the vicinity of the rising gas bubbles. If the fluid in the general vicinity of the rising bubbles may be visualized as somewhat more viscous than at more remote points in the water, the generally depressing effect of viscosity on turbulence should occur. In fluid mechanics, Reynold's Number is an important criterion of turbulence, and Reynold's Number and turbulence both decrease with increasing viscosity. Some of the reduced turbulence about gas bubbles rising in solutions of surfactants may be traced to their smaller size, as compared to the bubbles occurring in the absence of the surfactant, when air is supplied at the same rate. However, for the same rate of supply of air, the total surface area of the bubbles, per unit volume of air, would increase inversely as the diameter decreased. In addition, the total surface area of all bubbles in the column at any instant would be further increased by the decreased terminal velocity of the rising bubbles, since each bubble would remain in the system for a longer period of time. In the absence of surface active agents, smaller bubbles are a desired goal in bubble aeration because they are known to promote the rate at which oxygen can be supplied to the system. Any effect of surfactants on turbulence appears to operate in an adverse direction.

Summary and Conclusions

A number of types of synthetic detergents, and particularly the surface active agents which comprise their major active constituent, have been studied in laboratory apparatus with reference to their influence on oxygen transfer in bubble aeration. A gross coefficient of oxygen transfer for the experimental system has been used to evaluate the relative effects of the surfactants, the types of water used, and various additive salts and builders. From the results of this research and the applicable theoretical considerations, the following conclusions are drawn:

1. Synthetic detergents profoundly affect oxygen transfer in bubble aeration, usually in an adverse fashion.

2. The effects of synthetic surface active agents on oxygen transfer were found to be in general agreement with their surface activity, as measured by the criterion of surface tension, increased surface activity, and decreased surface tension resulting in increased interference with oxygen transfer.

3. For three homologous series of alkyl benzene sulfonates, the gross coefficient of oxygen transfer exhibited a generally decreasing trend as the number of carbon atoms in the alkyl chain increased.

4. The secondary and polypropylene benzene sulfonates showed more nearly uniform oxygen transfer coefficients for adjacent members of each series than the straight-chain alkyl benzene sulfonates with normal attachment to the benzene ring.

5. The presence of salts in water influences the effect of most surfactants on oxygen transfer significantly. For the alkyl benzene sulfonates, salts causing hardness in water generally caused adverse effects in addition to those occurring when the water contained no salts or only sodium salts.

6. Sodium tripolyphosphate builder caused additional reduction in oxygen transfer in the presence of the polypropylene benzene sulfonates, but only small or insignificant changes for the straight-chain types.

7. The effect of a surfactant on oxygen transfer is a function of the character of its hydrophilic group as well as of its hydrophobic portion.

8. To explain the effect of surface active agents on oxygen transfer in bubble aeration, major importance is attached to the surface viscosity of the films resulting at the air-water interface in the presence of surfactants.

Acknowledgments

The investigation described herein was supported by a grant from the National Institutes of Health, U. S. Public Health Service.

The assistance of all who supplied the various surface active materials used in this research is gratefully acknowledged. The suppliers of the several materials are acknowledged at appropriate points in the main body of the paper, but special thanks are due the Continental Oil Company for supplying the refined alkyl benzene sulfonates.

The time-saving assistance of the Computing Center of Cornell University is gratefully acknowledged.

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Industrial Wastes

SUBSURFACE DISPOSAL OF SALT WATER FROM OIL WELLS *

By W. S. Morris

Vice-President and General Manager, East Texas Salt Water Disposal Company, Kilgore, Texas

The disposition of salt water that is produced along with oil is probably the most troublesome problem in the oil producing industry in the United States today. It has been estimated that over six billion barrels of salt water were produced from oil wells in this country in 1956 (1). In order to visualize this volume it may help to know that this amount of salt water would fill a rectangular tank 100 ft deep, 1,000 ft wide, and 60 miles long. If this much water were evaporated, the salts remaining would weigh about 125 million tons—a cube about 1,250 ft on a side—and give every person in the United States about 100 cu ft of salt to eat! Thus, it is obvious that salt water is really a problem of great magnitude to the oil industry.

The oil industry is celebrating the 100th anniversary of the discovery of oil in the United States this year. In the early life of the petroleum industry kerosene, known as "coal oil" or "lamp oil," was the principal product of refining, and gasoline was the undesirable waste product. The development of the internal combustion engine solved this problem, although a surplus of gasoline is still possible.

With the coming of the atomic age, additional complex problems involving the disposal of radioactive wastes have plagued that industry. Some radioactive waste materials are solids, some are liquids, and some are gaseous. A committee from the oil industry has concluded that liquid radioactive waste can be safely disposed of by injection, through deep wells, into porous rocks (2).

Characteristics of the East Texas Oil Field

The East Texas oil field is located in parts of five counties in the northeastern part of the state. It was discovered in 1930, and approximately 30,000 wells were drilled there, 20,000 of which are still producing oil. It is the largest oil field in the United States and originally contained over six billion barrels of oil; to January 1, 1959, over 3 billion, 350 million barrels had been produced. The productive zone is the Woodbine sand at a depth of about 3,700 ft below the surface. The formation has an average porosity of 26 per cent and a permeability of about 2.6 Darcies. The pressure in the oil reservoir is derived from water pressure as shown in Figure 1, a generalized west-to-east cross section of the East Texas oil field. A water drive is apparent from this illustration, which also shows why large volumes of salt water will be produced when the oil is withdrawn from the wells. In 1958, the East Texas field produced an average of 142,812 bbl of oil and

* Presented at the 32nd Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Dallas, Tex.; Oct. 12–15, 1959.

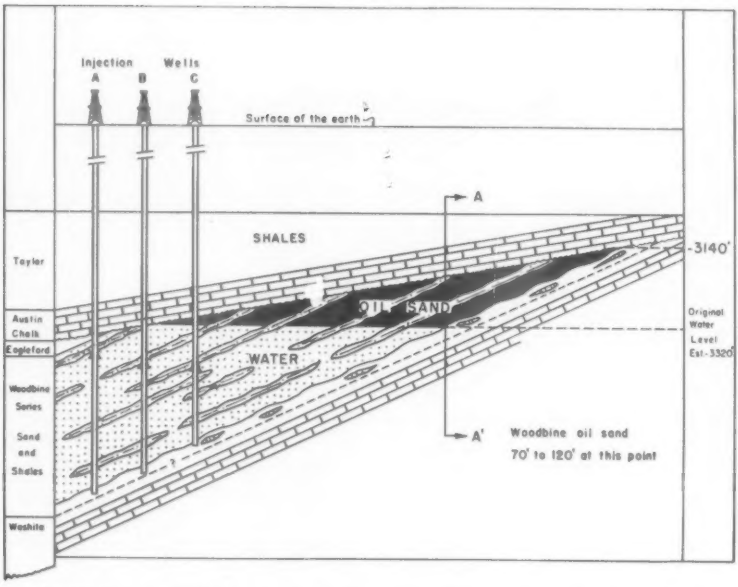

FIGURE 1.—Simplified West to East cross section of East Texas Field.

458,318 bbl of salt water a day. This is a ratio of 3.2 bbl of water for each barrel of oil. What to do with the waste salt water is the problem facing the oil producing industry.

Early Water Production and Methods for Disposal

Some salt water was produced early in the life of the field when wells were drilled below the oil-water contact, especially on the west side of the field, where the oil-sand section was relatively thin. By October 1935, approximately 15,000 bbl of salt water had been produced a day. In the latter part of 1938, when water production had reached 100,000 bbl/day, serious attention was directed to the problem of not only "salt water disposal," but also "pressure maintenance" in the reservoir. By the end of 1939, salt water production was about 200,000 bbl/day, and by the middle of 1941, had exceeded 400,000 bbl/day (3). Salt encroachment in the field is shown in Figure 2 as the shaded portion.

Late in 1939 an injunction suit to prevent salt water pollution of the fresh-water streams in the East Texas field drainage area directed wide attention to the salt water problem. As a result, many earthen pits for impounding the salt water were constructed, but by no means solved the problem from a practical standpoint. Salt water escaped from some earthen pits and found its way into the surface drainage of the area. Under conditions of this kind, trees and vegetation were killed and streams were polluted. Figures 3 and 4 show the results of salt water contamination to surface growth.

By the middle of 1941, plans for a field-wide program of salt water disposal were beginning to take shape. The war brought into sharp focus the need for salt water disposal and pressure maintenance in the field.

It was evident that some method of controlling the salt water production

had to be found or methods worked out to dispose of the water after it had been produced above ground. It was first thought that the water could be evaporated in open pits in the field, but the idea was soon discarded when it was found that the rate of evaporation in East Texas was practically equivalent to the rate of rainfall. Various methods of disposal of salt water included:

1. Evaporation in open pits.
2. Evaporation in open pits with the aid of heat (gas flares).
3. Continuous discharge of salt water into surface drainage and streams.
4. Storage of salt water in earthen pits within the field, with controlled discharge into streams during periods of heavy rainfall.
5. Transportation of salt water from the field to the Gulf of Mexico by pipe line or open ditches.
6. The injection of salt water into subsurface formations.

Each of the possibilities was explored; the first five methods proved unworkable. Early in 1936, the feasibility of returning salt water to the Woodbine sand in East Texas field was demonstrated in a test well, west of the producing limits of the oil field and in the south end of the field. The results of this large-scale experiment pointed the way for the salt water disposal program now in use in the field.

However, the cost of providing salt water treating plants and injection wells was so great that only the larger oil companies with large leases or groups of leases in one locality could afford to make use of the method of disposal.

Subsurface Disposal

The first injection well started operation in June 1938. The success of this method was soon evident, and other operators began installing the necessary facilities to return the water to the Woodbine sand. The method

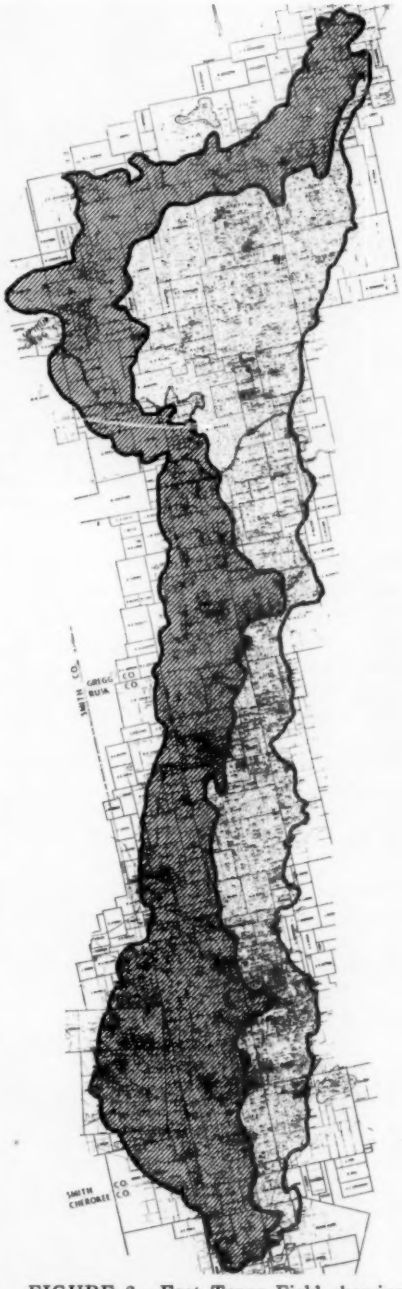

FIGURE 2.—East Texas Field showing salt water encroachment as represented by shaded portion.

FIGURE 3.—Damage to vegetation caused by salt water waste on ground surface.

was generally accepted by all operators and encouraged by the Railroad Commission of Texas. Since 1938 the program rapidly expanded, as shown in Table I.

To meet the need of all operators, both large and small, for salt water disposal facilities on a field-wide basis, the East Texas Salt Water Disposal Company was organized in January 1942, as a corporation under the laws of the State of Texas where such a salt water company is considered in the nature of a public utility under the Statutes of the State. Approximately 250 large and small operators in the East Texas oil field subscribed for stock in the company. It was early fall in 1942 before the Company became fully organized and ready to begin operations. On October 1, 1942, the Company injected the first barrel of water. At the end of 16 years and 3 months (to January 1, 1959) over

FIGURE 4.—Vegetation damage and erosion from salt water waste.

one billion, 874 million bbl of water had been injected through 60 injection wells. The Company has over $6 million invested in over 390 miles of pipe lines, 35 treating plants, 64 collection centers, 212 centrifugal pumps, and other equipment necessary to take salt water from the tank batteries of the operator, transport it to central points where it is treated to chemically stabilize it, and return the water to the underground reservoir through wells drilled especially for that purpose. Table I shows the growth of operations. Table II shows the number of injection wells, the number of leases and wells served by the disposal facilities, and the volume of water injected since the start of the injection program.

When an area of the oil field is to be served with salt water collection lines, the pipe lines are laid so as to take advantage of gravity flow whenever possible. The water is collected at central points in such a system and then pumped to the nearest treating plant for processing before being delivered to the injection wells. Figure 5 shows a plan of the collection system, treatment sites, and injection wells for one producing area. Figure 6 shows how the collection lines are placed on the ground surface. Scrapers are run at regular intervals to keep the lines clean (4).

TABLE I.—Growth of Subsurface Salt Water Disposal Systems in East Texas Oil Field

Year	Injection Wells	Salt Water Returned to Reservoir (bbl)	
		Total	Daily Avg
1938	1	223,953	611
1939	10	2,250,761	6,166
1940	31	10,965,941	29,962
1941	47	23,530,817	64,486
1942	49	29,399,277	80,546
1943	64	73,623,337	201,708
1944	74	124,153,141	339,216
1945	76	137,155,539	375,769
1946	77	156,005,547	427,412
1947	78	180,626,665	494,868
1948	80	190,811,133	521,342
1949	81	184,616,830	505,800
1950	81	170,263,050	466,474
1951	78	149,762,005	410,307
1952	78	148,632,745	406,100
1953	78	143,971,233	394,442
1954	78	145,861,968	399,622
1955	85	153,701,131	421,099
1956	87	160,291,017	437,954
1957	84	164,113,047	449,625
1958	82	164,879,041	451,723
Total		2,514,837,278	—

Treatment of Salt Water for Subsurface Injection

A natural question arises as to why salt water produced with the oil from the East Texas oil field needs treatment before return to the Woodbine sand. The salt water, when available for return, has been exposed to the air and is not exactly the same as when produced. When salt water leaves the underground reservoir, where it had been impounded for millions of years, and is brought to the surface and exposed to the atmosphere, the temperature is changed from 146°F to atmospheric, and the pressure is reduced from an average of 1,048 psi to atmospheric pressure. In addition, the carbon dioxide and petroleum gases dissolved in the salt water are allowed to escape; oxygen and other elements in the air mix with the elements of the salt water. The different characteristics make the salt water unstable. Consequently, treatment to remove oil and foreign substances is necessary before it can be returned with a minimum of difficulty to the underground sandstone reservoir. Specific reasons for treatment are outlined below.

Composition of Salt Water

The salt water in the East Texas oil field contains several compounds that result in a deposit of a scale, and, if this scale should be deposited in the well, the pores in the sand would become clogged, and would reduce the effectiveness of injection. The scale is removed by chemical treatment. Table III shows a mineral analysis of the

TABLE II.—Salt Water Injected by East Texas Salt Water Disposal Company

Date	Facilities Furnished		Injection Wells	Salt Water Injected (bbl)		Total Cost per Barrel—Before Taxes (¢/bbl)
	Leases	Wells		Total	Daily Avg	
1942 (3 Mo.)	27	208	8	577,412	6,276	7.160
1943	382	2,100	30	40,593,672	111,216	1.719
1944	454	2,372	34	79,279,702	216,611	1.404
1945	480	2,776	34	88,267,231	241,828	1.429
1946	501	3,126	41	110,353,193	302,338	1.422
1947	512	3,374	45	136,266,014	373,332	1.359
1948	487	3,334	47	144,224,988	394,057	1.384
1949	502	3,482	51	142,859,378	391,396	1.454
1950	508	3,396	54	135,439,492	371,067	1.437
1951	522	3,360	53	122,379,116	335,285	1.522
1952	510	3,324	52	121,447,415	331,824	1.417
1953	522	3,317	55	115,219,409	315,670	1.363
1954	552	3,468	54	116,442,798	319,021	1.457
1955	594	3,803	59	125,957,707	345,090	1.339
1956	621	3,707	60	131,944,238	360,503	1.335
1957	690	3,995	60	135,145,949	370,263	1.361
1958						
January	692	3,944	59	11,298,308	364,462	1.341
February	696	4,026	59	10,244,237	365,866	1.432
March	705	4,080	59	11,276,968	363,773	1.229
April	705	4,085	59	10,987,790	366,260	1.370
May	712	4 092	59	11,196,900	361,190	1.545
June	711	4,077	59	11,172,023	372,401	1.473
July	719	4,092	59	11,728,893	378,351	1.383
August	721	4,068	59	12,010,344	387,430	1.340
September	720	4,102	59	12,019,046	400,635	1.534
October	715	4,111	58	12,207,929	393,804	1.477
November	722	4,112	59	11,769,785	392,326	1.258
December	714	4,125	60	12,254,385	395,303	1.330
1958 total	—	—	—	138,166,608	378,539	1.392
Total	—	—	—	1,874,455,059	—	—

salt water as reported by Plummer (5).

The analysis in Table III indicates that the water is high in sodium and chlorides, and contains enough calcium bicarbonates to be scale forming. The troublesome elements are the ones which, when oxidized by air, form insoluble precipitates. The chemical treatment of the salt water is designed to precipitate the insoluble compounds and remove them by settling.

TABLE III.—Chemical Composition of Salt Water in East Texas Oil Field

Component	mg/l	Reaction Values
Sodium	22,050	958.8
Calcium	1,176	58.7
Magnesium	197	16.2
Sulfates	384	8.0
Chlorides	36,400	1,026.6
Carbonates	0	0.0
Bicarbonates	366	6.0

Very little iron (in solution) is contained in the salt water while in the reservoir, but the concentration is increased after the water has passed through the operator's steel tubing, flow lines, and treating systems. Certain microorganisms are found in the salt water after it is produced, and are known to play an important role in the formation of the insoluble precipitates (6).

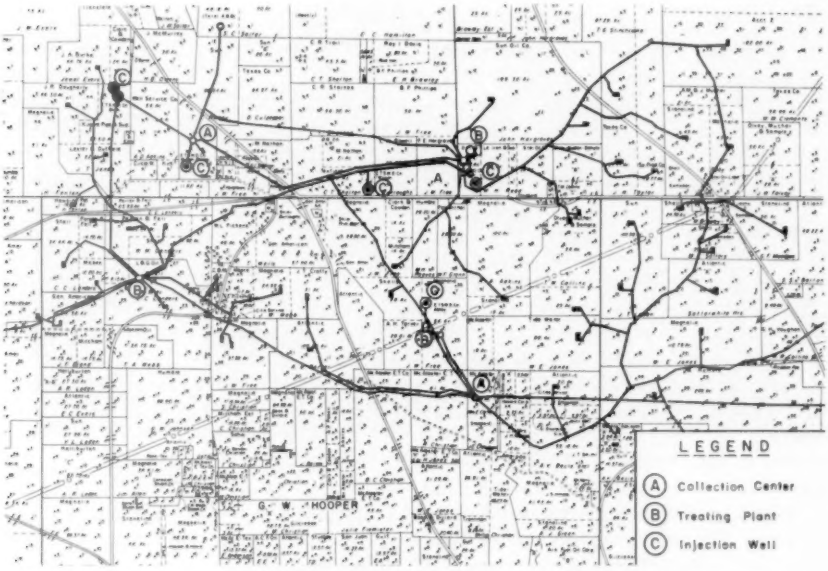

FIGURE 5.—Plan of collection system, treatment sites, and injection wells for one producing area.

FIGURE 6.—Typical installation of collection lines.

Skimming

When the salt water enters the gathering system, it contains some oil in the form of microscopic spherical droplets and also larger particles intimately mixed with the water. Often larger amounts of oil are received, either as waste oil or oil that has been mechanically entrained by the salt water. The quantity of oil is so great that skimmers are required for its removal. When the water enters the skimming devices, it is in a turbulent state and usually in the form of an emulsion or foam. At this point, the larger particles of oil separate and rise to the surface, but the smaller particles remain in suspension. By the use of baffles in the skimming device, the smaller particles are gradually removed. The layer of oil that accumulates on the surface of the water is removed by the skimmers into an earthen pit.

Aeration

Because of the use of "open-type" systems, it has been necessary to aerate the water thoroughly in order to treat it economically. The primary purpose in aerating the salt water is to oxidize the soluble ferrous compounds to insoluble ferric compounds that precipitate. A high aeration efficiency tends to lower the chemical cost required to treat the salt water. Oxidation tends to change the soluble bicarbonate compounds to insoluble carbonate compounds which settle out in the pits or are retained in the filters. Bacterial activity is somewhat reduced because of the lowered temperature of the water after aeration. Although oxidation is never carried to completion, it is the most important single function used in the treatment of the salt water.

Chlorination

Early in the period of development it was learned that a powerful oxidizing agent was needed to control algae and bacterial growths and aid in the further oxidation of iron (5). Chlorine was found suitable for this purpose. Although the concentration used does not kill the sulfate-reducing bacteria, the algae growth is inhibited and the chlorine materially aids in the oxidation of the ferrous iron. An attempt was made to operate without chlorine, but it was found that the salt water in the treating plant became unmanageable because of organic growth. Moreover, the injection wells began to decrease in their capacity to take water.

Chemical Treatment

The primary purpose of the chemical treatment of the salt water for subsurface injection is to remove the compounds that would form on the face of the sand in the injection well. After the salt water is aerated, it flows into the treating pits in a turbulent state where chemical additions are made. Iron compounds, calcium compounds, and small amounts of hydrocarbon products are the principal materials necessary to remove.

Hydrated lime and alum are used in the chemical precipitation operation. Lime is added from dry chemical feeders, which discharge into funnels where salt water is circulated. Alum is added along with the lime, also by dry chemical feeders. The resulting floc is settled and the supernatant is decanted.

Operating experience reveals that the average chemical dosage amounts to about 8 to 12 lb of lime per 1,000 bbl of salt water and from 8 to 12 lb of alum per 1,000 bbl of salt water treated. These dosages are designed for 24-hr settling.

Design Details

A standard rectangular basin is used for flocculation and sedimentation. It is 133 ft long and 66 ft wide, with

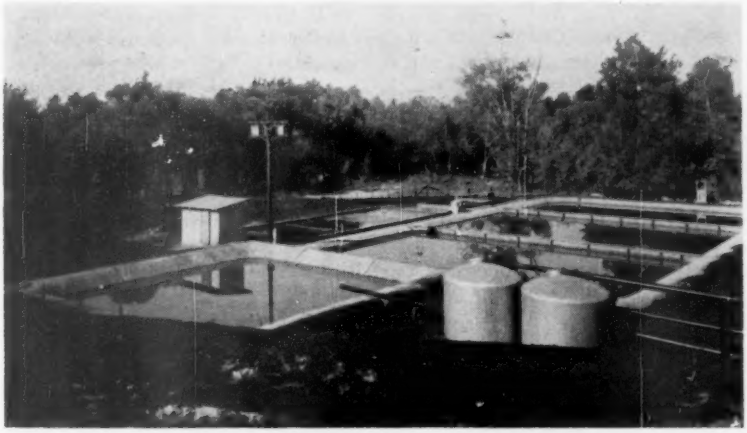

FIGURE 7.—Typical salt water waste treatment plant.

the sides constructed on a 1½:1 slope, giving it a depth of 10 ft.

These basins are designed to provide 10,000-bbl capacity and a 24-hr detention period. Detention periods under 12 hr have been found undesirable for economic and efficient operation.

Each basin is equipped with two oil skimmers in each section. A basin is also equipped with one under baffle in the first section, and two over-and-under baffles in the other two sections. The baffles are made of untreated yellow pine, and are fastened with galvanized fittings. The outlet header is a slotted 10-in. asbestos-cement pipe placed 4 ft below the top of the pit. The pit is constructed of reinforced gunite and poured concrete. The cost of the rectangular type pit was approximately $10,000, or $1.00 for each barrel of treating capacity per day.

Figure 7 shows a complete treatment unit. The waste salt water enters the basin at the far left where aeration occurs. The chemical precipitation and settling facilities are in the right center, and the pressure filters are in the right foreground.

Cost of Treatment

The average cost for treating salt water with chlorine-alum-lime and sodium aluminate for the year 1957 was 0.437 mill per barrel, and 0.523 mill per barrel in 1958.

Filtration

Some small floc particles tend to remain in suspension in the effluent from the chemical precipitation. If these particles are allowed to pass into the injection well, the sand face becomes clogged in a short time. To prevent such clogging, pressure filters are used to remove these particles.

The pressure filters use steel shells 96 in. in diameter and 54 in. high, with dished heads on each end, and are designed for a working pressure of 45 psi. The filters are upright and are supported by screw jacks.

Crushed and graded anthracite coal, as well as sand and gravel, is used as a filtering medium. The filtration rate of the anthracite coal is 4.0 gpm/sq ft, while the rate for sand and gravel is 3.0 gpm/sq ft. The coal medium costs more than sand and gravel but its filter rate is greater and its service life is approximately two years. When a high backwash rate is used, a small part of the coal medium is washed out of the filter, because of its light weight (approximately 40 lb/cu ft). This

does not take place with sand, for it weighs approximately 100 lb/cu ft.

The minimum backwash rate used is 10 gpm/sq ft and the maximum rate is 13 gpm/sq ft of bed area. An excessively high backwash rate will tend to unload the filter medium but an abnormally low backwash rate will cause the supporting filter medium to become cemented.

Results of Program

The history of the production to pressure relationship in the East Texas field is summarized in Figure 8. Data are tabulated on this chart from the year 1930, when the field was first discovered, through the year 1958. The original pressure in the reservoir was 1,620 psi. This pressure had declined to approximately 1,000 psi before serious attention was directed to the return of the salt water to the reservoir. It is shown that the pressure remained fairly constant after the salt water disposal program was inaugurated and at the end of 1958 had actually risen to 1,050 psi.

The lower section of the chart shows pertinent data with respect to the oil production, salt water production, and salt water injection. The top section of the production curve shows the volume of water injected and indicates that better than 98 per cent of all water produced in the field is returned to the reservoir. At the time the injection program described herein was initiated two main purposes were advocated: (*a*) the elimination of pollution of surface waters and streams, and (*b*) the maintenance of reservoir pressure. At this time the oil field is practically free of contamination and pollution by salt water and the streams that drained the area of the oil field are once again inhabited by fish. The average reservoir pressure has shown a gradual increase as discussed above, with better results than had been anticipated.

Summary

The organization and execution of the salt water disposal project to return salt water, from all operators in the oil field, to the Woodbine sand res-

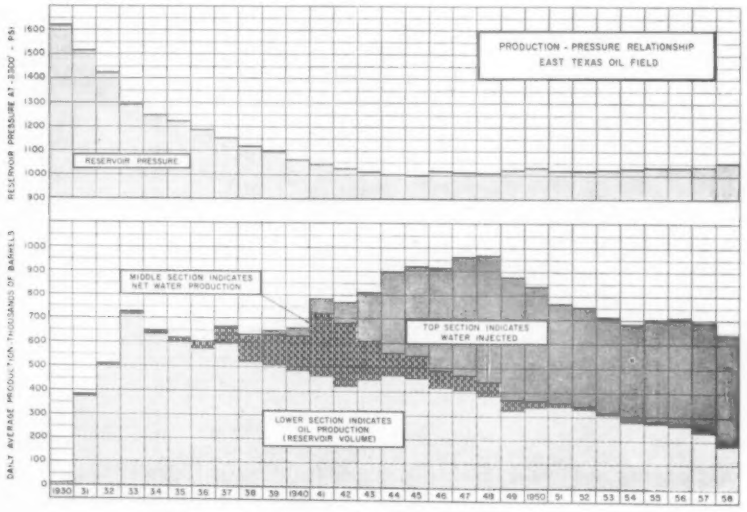
PRODUCTION - PRESSURE RELATIONSHIP
EAST TEXAS OIL FIELD
RESERVOIR PRESSURE AT -3300' - PSI
RESERVOIR PRESSURE
DAILY AVERAGE PRODUCTION-THOUSANDS OF BARRELS
MIDDLE SECTION INDICATES NET WATER PRODUCTION
TOP SECTION INDICATES WATER INJECTED
LOWER SECTION INDICATES OIL PRODUCTION (RESERVOIR VOLUME)
1930 31 32 33 34 35 36 37 38 39 1940 41 42 43 44 45 46 47 48 49 1950 51 52 53 54 55 56 57 58

FIGURE 8.—Production-pressure relationship in East Texas Oil Field.

ervoir on a field-wide basis, is a significant and outstanding conservation and water pollution control measure. The oil operators in the East Texas field and the Railroad Commission of Texas have shown excellent cooperation in working out a successful answer to a most difficult problem. In addition to the benefits derived by the elimination of pollution of the streams, the return of salt water to the reservoir has maintained the bottom-hole pressure to the extent that many wells have continued to flow that otherwise would have required mechanical lifting.

It is estimated that as a direct result of the salt water disposal program, more than 600 million barrels of additional oil will be recovered from the reservoir (7)(8)(9). An oil field with 100 million barrels recovery is considered a major field in the oil industry. The addtional oil to be recovered from East Texas is therefore equal to the equivalent of six major oil fields.

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DUES FOR 1960

To those whose 1960 dues are not yet paid please read on. Those whose names have not been submitted on a paid list by a Member Association Secretary by February 1 will not receive a JOURNAL after the January issue. If the dues are received after this date another series of clerical procedures is necessary to reinstate the member. This invariably means a delay in getting several of the JOURNAL issues to the member and is an added cost to the Federation.

The only way to avoid the inconvenience of delays is to make certain that your Association Secretary has your dues in sufficient time to forward to the Federation office. This means your Secretary must receive payment by January 25.

Your Secretary is listed on page 6a of this issue.

TREATMENT FACILITIES FOR THE PHOTOENGRAVING INDUSTRY

By Wayne A. O'Shana

Industrial Waste Inspector, Los Angeles Sewer Maintenance Section, Los Angeles, Calif.

The photoengraving industry's recent introduction of powderless etching machines in the City of Los Angeles prompted a complete reappraisal of the treatment of wastes from this industry.

For several years the low pH wastes from photoengraving shops have been treated by clarification and neutralization with calcium carbonate, usually in the form of marble chips placed in the first two compartments of the standard 3-compartment 6- × 2- × 2-ft clarifier. However, the bath from powderless etching machines contains an oil which coats the marble chips and very effectively inhibits any reaction with the nitric acid. As a result, treatment is poor. The acid then attacks the treatment equipment and the discharge lines. As an example, in one instance, a 4-in. inverted elbow in a clarifier was "cut-off" at the waterline; fortunately, the clarifier was made of redwood and was not damaged. Unfortunately, the sewer was not made of redwood. Another shop has a concrete clarifier which will no longer hold water, and as might be expected, the sewer was fast approaching the same condition. In both cases the downstream manholes had their concrete waterways damaged. Another shop has been forced to replace a clarifier since installation of a powderless etching machine.

Powderless Etching Machines

Powderless etching machines are supplied in several sizes—ranging from an 84-liter bath to a 135-liter bath. In operation the baths are constantly recirculated to maintain a homogeneous mixture, and are temperature controlled to provide one measure of control to the etching process. Bath temperature controls the shoulder angle of the bite.

The makeup for a 128-liter bath for zinc etching is as follows:

17.75 liters of 42 Bé nitric acid,
4 liters of solvent (sulfated castor oil mixture in 2:1 ratio), and
Water to make 128 liters.

The solvent and oil are supplied under several trade names, but it is believed that the mixture would contain the following ingredients:

Water,
Aromatic petroleum naphtha,
Sodium sulfate,
Sodium sulfates and sulfonates of the glyceryl esters of ricinoleic acid, stearic acid, oleic acid, palmitic acid, and linoleic acid.

This mixture is a filming agent and serves the same purpose as the previously used etching powder in that it prevents undercutting of the face of the zinc plate as the nitric acid bite progresses.

During use acid may be added to the bath after each plate is removed in the ratio of one ounce of acid to one ounce of metal dissolved. It might also be necessary to replenish the solvent about twice during the life of a bath with additional nitric acid each time. Depending on the work load, these machines are usually dumped about once or twice per day.

The powderless technique is also

used to etch magnesium with different additives in the nitric acid bath. These additives may be dioctyl sodium-sulfosuccinate (filming agent), diethylbenzene (solvent), sodium sulfate, and gelatin.

The powderless etching of copper is not common at this time—only two such machines are known to be in Los Angeles. This process differs from the above in that the filming agent is chemically formed by the reaction between an additive and the copper metal as it dissolves. The additive is a derivative of thiourea which reacts with cuprous chloride—a product of copper etching—to form a gelatinous precipitate which coats the bare copper metal. A 30 Bé ferric chloride bath is used in this operation.

Treatment Needs

When the marble chips proved to be worthless for pH control, it was necessary to find some method that would meet the following requirements:

1. Means for providing pH adjustment to the waste between the range of 5.5 and 9.0 prior to final discharges.
2. Quick, simple, low cost installation and operation.
3. Prevention of noxious fumes or excessive sludge as by-products of the neutralization reaction.
4. Minimum floor space (most engraving shops are already crowded).

Recommendations

To meet the minimum requirements a holding tank in which all acidic waste can be collected and batch treated with soda ash seems to be a reasonable answer for the photoengraving industry.

Soda ash has proved to be the best neutralizing agent so far encountered in that it is quick acting and produces a minimum of sludge. Its use requires some care, however, since excessive foaming results from bulk application. It has been found best to sprinkle two or three pounds at a time over the surface of the waste. There is a strong temptation to use materials which are lower in cost than soda ash, but unless a comparably low sludge production results, the lower cost is not justified.

One shop has provided compact, economical treatment by constructing a 6-ft × 28-in. × 7-in. redwood holding tank alongside the powderless machine and then mounting the usual plate washing and rinsing sink over the tank. A tank of this size is adequate for an 84-liter machine. This double-deck arrangement has another advantage; the sink drains directly into the holding tank and the sulfuric and nitric acids used for plate cleaning are also collected for treatment.

When it is not convenient to drain the sink into a holding tank, the sink can be stoppered and used as a holding tank. It is advisable to raise the wooden duckboards about six inches above the sink bottom and treat the waste for discharge when it reaches that height.

It is also recommended that water conservation be practiced by the installation of automatic shutoff valves for all rinsing operations, and particularly those of an acid nature which are collected in the holding tank. Obviously, the smaller the volume of waste collected, the smaller the holding tank required. Also, fewer interruptions in the work schedule will be required to treat and empty the tank.

Treating the waste in the machine before discharge is not recommended. Most of the oil in the bath becomes soap-like after neutralization and tends to dissolve or disperse in the aqueous solution. However, some of it tends to form a sticky, curd-like substance which would be difficult to clean from the machine.

Attempts to avoid the installation of a holding tank usually follow the reasoning that the waste can be ade-

quately treated by adding soda ash to the clarifier as the machine is dumped, or by adding soda ash to the waste flow some place between the machine and the clarifier. Thorough testing of these schemes has conclusively proved that they cannot consistently provide the required pH control.

The above remarks apply with equal validity to the treatment of waste from powder-type etching machines. These machines discharge a 16- to 20-gal bath containing 1 to 2 gal of nitric acid for zinc etching and about the same bath volume of 42 Bé ferric chloride for copper etching. The sensitivity of marble chips to contamination and their subsequent ineffectiveness for pH control have been noted. The sludges from copper etching and neutralization reactions quickly ruin such a system. Even under the best of conditions, as far as quality of waste is concerned, the marble chip treatment system can be considered marginal. Unless freshly installed, the reaction is so slow that the waste must remain in the clarifier for at least one-half of the theoretical one-hour retention time. The machines are dumped very quickly and then rinsed with a large volume of water which tends to pass the waste through the clarifier in 5 to 10 min. This explanation also might explain why the last compartment of a clarifier may have a pH of 2, when the first two compartments are full of marble chips.

In some shops which were found to have no clarifiers or treatment facilities of any kind, it was recommended that their large sinks be stoppered and used as neutralizing tanks for spent etching baths which could be pumped from the machines. This would apply to powder-type machines only. It might also be important to collect and treat the rinse water from powder-type etching operations. Tests have proved this waste to average a pH of about 3 to 4.

Summary

In summary, it is recommended that all low pH waste from photoengraving operations be collected and treated in holding tanks before discharge to the city sewerage system. Final pH of the waste should be within the range of 5 to 9. Suggestions for providing these conditions are offered and examples from a city study are cited.

AIR POLLUTION RESEARCH PROJECTS

The American Society of Mechanical Engineers Task Group on Research in Air Pollution is continuing a compilation of active air pollution research projects.

The task group sent questionnaires during December; however, they felt that they were unable to reach all the organizations and personnel actively engaged in air pollution research.

This is an appeal to those researchers and research organizations who want to be included in the survey to get in touch with:

Mr. Austin Heller, Chairman
Task Group—Air Pollution Research
American Society of Mechanical Engineers
29 West 39th Street
New York 18, N. Y.

SPRAY IRRIGATION OF WOOD DISTILLATION WASTES *

By R. C. Hickerson and E. K. McMahon †

Tennessee Products & Chemical Corporation, Nashville, Tenn.

The Wrigley plant of the Tennessee Products & Chemical Corporation, located about 40 miles southwest of Nashville, produces charcoal, acetic acid, wood alcohol, and various wood oils and tars. Blocks of hardwood, primarily oak and hickory, are heated in large air-tight iron retorts. The wood is converted into charcoal, and the volatile materials driven off the wood are condensed as pyroligneous acid. Tar is allowed to settle out of the pyroligneous acid, and the water layer is fed to a continuous distillation column. The low boiling overhead material from this distillation is the crude wood alcohol. The later refining of this crude wood alcohol results in two wastes called "Lime Lee waste" and "alcohol pot residues."

Returning to the distillation column, the higher boiling material discharged from the bottom is a weak water solution of acetic acid and other organic materials (higher acids and phenolic materials). This water solution is extracted with ethyl acetate. Stripping the ethyl acetate, which is then recycled, results in crude brown acid. The later refining of this acid, and the associated wood oils, results in two wastes called "water column waste" and "decanter overflows."

The manufacturing plant has a capacity of around 200 cords/day. (A cord is a volume measure of wood on the order of 2½ tons in weight, depending on water content of the wood.)

* Presented at the Annual Meeting of the Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.; Memphis, Tenn.; Sept. 22–24, 1958.

† Deceased August 1959.

Wastes from Manufacturing Operations

Table I includes a list of the various process wastes, showing volume and results of various tests applied to these wastes.

The Tyrosine test for phenolics is based on the ability of tannins, lignins, and other phenolic materials to reduce phosphotungstic and phosphomolybdic acids to produce a blue color suitable for colorimetric and photometric estimation. The test is outlined in "Standard Methods" (2). The effect of lower molecular weight phenolics is shown by Burk and Schroeder (3).

In addition to the above process wastes, plant runoff and condenser cooling water are discharged. These wastes are drained into a small creek called Warner Branch. The flow in this creek varies widely, from a minimum of around 0.5 mgd in the summer to a maximum of over 10 mgd. At a time when the creek flow was around 2.5 mgd, the BOD was 300 mg/l and the COD was about 125 mg/l. In appearance the water was black, with an actual platinum-cobalt color of around 200 mg/l. The phenolic content was approximately around 30 mg/l. The water was obviously contaminated.

The process wastes are divided as follows:

1. The Lime Lee and water column wastes account for most of the volume.

2. The decanter overflow wastes, with its high phenolic content, accounts for most of the color. This ma-

TABLE I.—Characteristics of Wastes from Manufacturing Operations

Waste	Volume (gpd)	Appearance	pH	BOD (mg/l)	COD* (mg/l)	Phenolics† (mg/l)	Ether Extractable Material (per cent by wt.)
Lime Lee	25,000	Pale greenish yellow	6.8	1,300	330	265	1.2
Alcohol pot residues	1,000	Dark brown	9.2	—	4,750	2,650	2
Water column	40,000	Tea colored	3.4	8,200	180	365	0.25
Decanter overflows	4,000	Yellowish brown (in absence of iron)	3.5	40,000	27,500	14,200	2.9

* Chemical oxygen demand is here determined with a cold acid titration with $KMNO_4$, using indigo carmin indicator (1).

† See text for description of analytical procedure.

terial, a pale yellow-brown when discharged, turned inky blue-black on contact with dissolved iron.

Laboratory Evaluations of Treatment Methods

Lagooning and aeration of the individual process wastes were tested in the laboratory. Various chemical methods, such as chemical precipitation, were tested to determine their effectiveness and cost feasibility. The various procedures are evaluated below for each process waste.

Lime Lee Waste

Lagooning, and lagooning with mild aeration, for 30 days resulted in no reduction in chemical oxygen demand. Treatment of the waste with 700 mg/l ozone was responsible for about a 50-per cent improvement. Adjusting the pH to 9 and digesting for 4½ hr at 90°C, followed by acidification with hydrochloric acid to a pH of 2 and retaining for 4½ hr at 20°C, resulted in a flocculent precipitate. After filtration, an 85-per cent improvement was seen in the chemical oxygen demand. Solvent extraction with ether at a feed ratio of 0.85 to 1 resulted in a clear effluent with a COD of only 3 per cent of that found in the starting material.

Alcohol Pot Residues

Thirty-day lagooning reduced the COD by 37 per cent, and lagooning with aeration reduced the COD by 54 per cent. The chemical precipitation treatment described above effected a 67-per cent improvement in COD.

Water Column

Thirty-day lagooning, with and without aeration, showed only a 6-per cent improvement in COD. Treatment of the wastes with 2,800 mg/l ozone destroyed most of the phenolic compounds, but did not materially affect BOD. Unsuccessful attempts were made to treat the waste by chemical precipitation.

Decanter Overflow Wastes

Thirty-day lagooning, and lagooning with aeration, of the raw wastes effected 15-per cent improvement in COD and no improvement in phenolic content. Treatment of the raw wastes with 25,000 mg/l ozone was responsible for substantial improvement in phenolics content but very little effect on BOD. Chemical treatment produced an improvement of 22 per cent in COD.

The waste, containing 14,000 mg/l of phenolic materials, forms the blue-black iron complex seen with tannin. The true tannins (molecular weight 1,500 to 2,500) form a colored floccu-

lent precipitate with iron salts under these conditions, whereas most lower molecular weight phenolics form colored complexes which do not precipitate. This complex is described (4) to result from the action between ferric iron and any phenolic compound to form a complex ion with three negative charges. When a telephone battery electric charge was placed across the ends of a glass U tube containing the inky material, the blue color migrated toward the positive pole and left the end of the tube around the negative pole relatively clear.

Another characteristic of this color complex is that acidification to a pH of about 2 breaks the complex and causes the color to disappear. On neutralization, the color re-forms. This blue-black iron complex is much more subject to oxidation than the raw phenolic waste.

Markedly different results were obtained on lagooning and on aeration between the raw wastes, and the waste which had been complexed with iron. Thirty-day lagooning caused a 30-per cent drop in COD and a 15-per cent drop in phenolics content. With 30-day aeration, a 75-per cent reduction was found in both COD and phenolics. This same improvement was found in small pilot plant studies where the complexed waste was pumped into a pressure vessel at around 100 psi and aerated at 150°C. In addition to the reductions in COD and in phenolic content, the ability of the waste to form the blue-black color was destroyed. In all cases a sludge amounting to 6 to 15 per cent by volume was formed, which would constitute a filtration problem.

Spray Irrigation

During the period of preliminary testing various reports were received about the successful handling of other wastes by spray irrigation. In accordance with the conditions encountered at this plant it was decided to initiate a program of spray irrigation for evaluation of the method using wood distillation wastes.

The information on other treatment methods is included because it was felt that the methods of treating phenolic wastes, especially, have some merit, particularly when comparatively high concentration of high molecular weight phenolics are encountered.

Greenhouse Tests of Spray Irrigation

To evaluate spray irrigation, a method of determining the effects of each of the separate wastes on various grass crops was necessary. To do this, it was decided to institute crop tests in a greenhouse. A small greenhouse was built (Figure 1), 6 ft wide, 12 ft long, and made of a 2-in. by 4-in. frame covered with chicken wire. A three-mil thick polyethylene sheet covered the chicken wire. The greenhouse was equipped with shelves, a scale, several sprinkler cans, about 150 open top one-gallon cans for the samples, and various garden tools as shown in Figure 2. An electric heater with thermostat was installed for temperature control.

The specific purpose of the greenhouse was twofold:

1. What type of pasture crop would be most suitable for irrigation?
2. Which process wastes could be irrigated without killing or stunting the plants?

Procedure

The plants tested included samples of established fescue and blue grass, and also samples of fescue, rye grass, and ladino clover grown from seed in the greenhouse. The samples were placed in 1-gal cans and contained approximately 10 in. of soil (Figure 3).

Samples of the individual plant process wastes were collected in 20-gal drums and neutralized with powdered limestone. The process wastes tested were Lime Lee, alcohol pot

FIGURE 1.—Test greenhouse used for preliminary spray irrigation studies.

residues, water column wastes, decanter overflow, and a composite of these.

The wastes were applied to the gallon cans in two ways: (a) by sprinkling over the grass, and (b) by addition to the soil through a funnel so that none of the foliage came into contact with the waste. The applications were twice per week, 250 ml per application. This amount was equivalent to 55 in./yr. The tests were continued for 32 weeks.

Results

After the first waste application it was seen that the alcohol pot residue would kill each type of grass. After the third application of decanter overflow waste, it was observed that this waste caused the grass to turn brown. The presence of decanter overflow waste in the composite did not kill the grass, but did stunt it.

The grasses treated with Lime Lee and water column wastes showed no detrimental effects.

"Kentucky 31" fescue withstood the action of the wastes better than the other grasses. Blue grass appeared to be satisfactory; rye grass and clover were unsatisfactory. Whether the waste was added by spraying or by pouring into the soil so as not to touch the leaves made little difference. Application of the decanter overflow wastes by soil addition took a little longer to kill the grass than by sprinkling it on the leaves, however.

From the limited tests it appeared that irrigation of fescue with Lime Lee and water column wastes would be successful.

As a result of the test program, the following spring a one-quarter acre of fescue and clover was sprayed intermittently with the two neutralized wastes blended in proportion to production rate. Since the results of waste application to the test plot were excellent, it was decided to proceed without delay with operation on a 40-acre field.

Full-Scale Spray Irrigation System

In the full-scale system the two plant wastes are fed to a neutralizing sump located between the plant and the

creek. The waste is pumped from the sump approximately three-quarters of a mile to a one-half acre retention pond or lagoon, adjoining the irrigation field. Waste is pumped from the pond through quick-coupling, portable aluminum pipe to spray nozzles. Spraying is done during daylight hours several days each week, depending on weather and pond level. Daily operating data are supplied to the Tennessee State Health Department, Stream Sanitation Division, in the form of a monthly report.

Preliminary Treatment and Handling

The sump is a concrete (bitumen lined), rectangular divided tank extending below ground level. It is divided in four sections, each containing about 5,000 gal. The first three sections are filled with limestone. The slightly acid water column waste is fed to the first section and passes through in series to the fourth section. During this period of contact with the limestone the water column waste pH is raised to about 5.8. Figure 4 shows water column waste being fed to the first section. The slightly alkaline Lime Lee waste is added to the fourth section, and lime is added to maintain a pH of around 6. This fourth section is equipped with an agitator and a level

FIGURE 2.—Inside of greenhouse showing crop samples.

FIGURE 3.—Crop samples as grown in greenhouse.

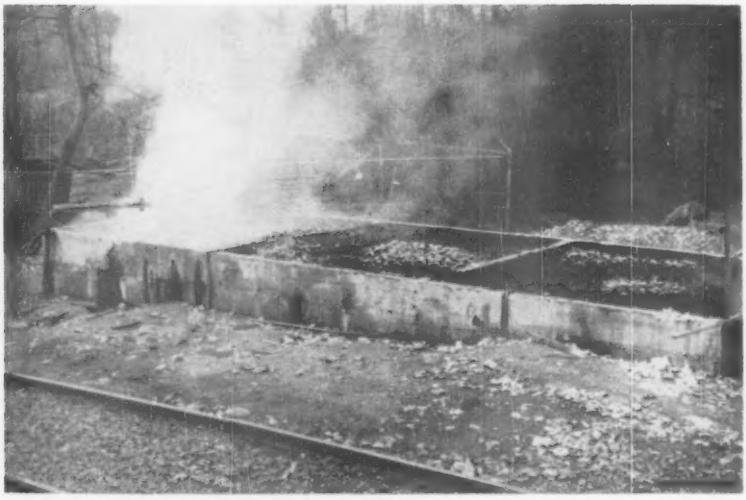

FIGURE 4.—Neutralization sump showing water column wastes being fed to section at left.

controlled device which operates a centrifugal pump. Figure 5 shows the fourth stage of the sump with lime feeder and pump which delivers the waste to the retention pond at the irrigation field.

The centrifugal pump shown in Figure 5 is rated at 80 gpm at 360 ft head, delivers the waste three-quarters of a mile to the retention pond at an elevation difference of 150 ft. A standby pump has been installed. The line

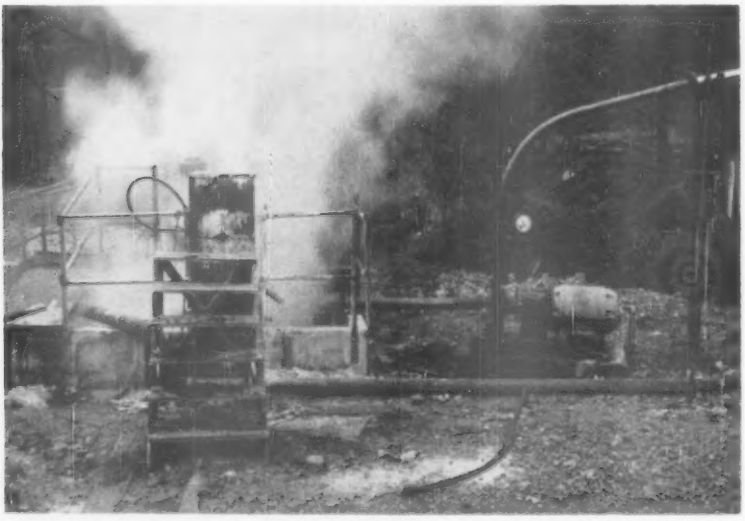

FIGURE 5.—Fourth stage of the neutralization sump, lime feeder, and pump which delivers the waste to holding lagoon.

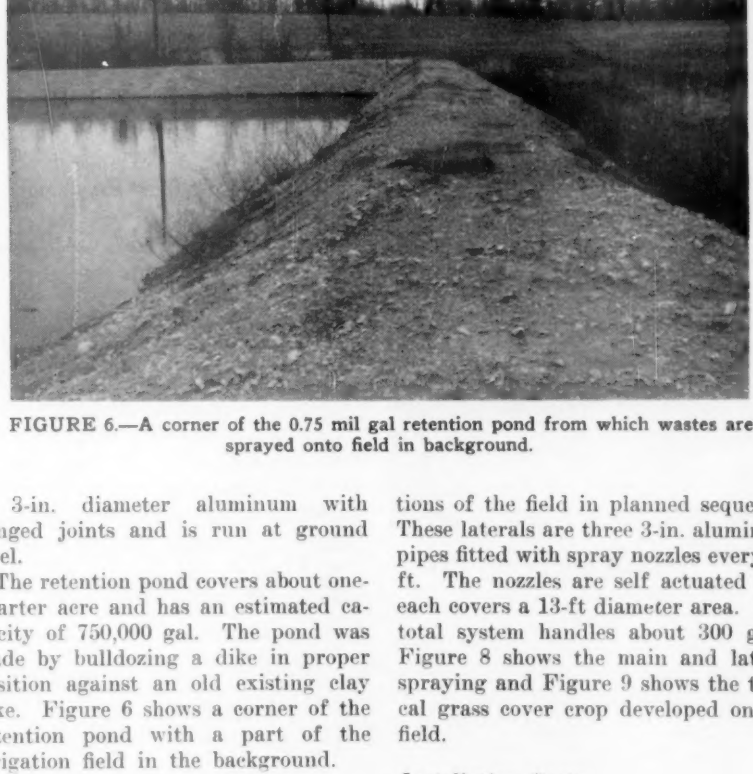

FIGURE 6.—A corner of the 0.75 mil gal retention pond from which wastes are sprayed onto field in background.

is 3-in. diameter aluminum with flanged joints and is run at ground level.

The retention pond covers about one-quarter acre and has an estimated capacity of 750,000 gal. The pond was made by bulldozing a dike in proper position against an old existing clay dike. Figure 6 shows a corner of the retention pond with a part of the irrigation field in the background.

Spray System

A centrifugal pump driven by a 50 hp motor, shown in Figure 7 draws wastes from the pond through a 5-in. aluminum above-the-ground main. This leads to the middle of the field and splits into two 4-in. aluminum feed mains. These feed mains run north and south and split the approximately square 40 acres with a total line length of 1,250 ft. At 60-ft intervals on these feed mains are quick-coupling fittings. Four movable lateral spray lines are connected to the feed main at locations chosen by the operator to permit spraying sections of the field in planned sequence. These laterals are three 3-in. aluminum pipes fitted with spray nozzles every 25 ft. The nozzles are self actuated and each covers a 13-ft diameter area. The total system handles about 300 gpm. Figure 8 shows the main and lateral spraying and Figure 9 shows the typical grass cover crop developed on the field.

Installation Costs

The sump, lines to the pond, spray system, pumps, and other items cost around $15,000, installed. This does not include land cost.

Operational Comments

Judgment must be exercised on selection of field areas for spraying and on the amount of wastes these areas can take. There are times when spraying should be delayed due to weather or due to condition of the field. During 1957, a relatively wet year, enough spraying was possible on the existing area to dispose of plant wastes without objectionable run-off.

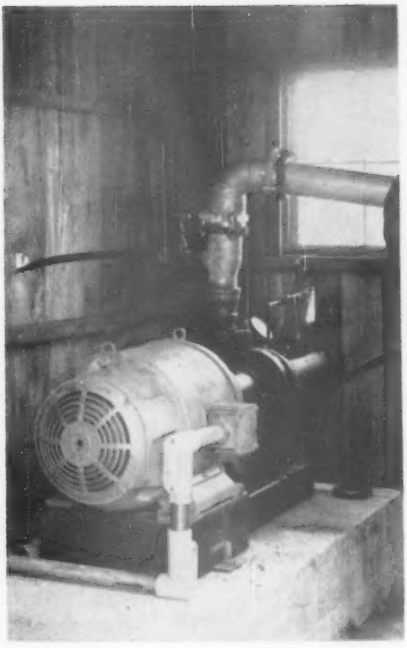

FIGURE 7.—Irrigation pump located at retention pond.

Several problems were brought out during the first two years. The first problem was a leaking retention pond. This became evident by testing the water in the drainage creek leading away from the spray irrigation field. The steps necessary to correct the leaks were recommended by the local soil conservationist, and consisted of putting a clay core behind the leaking dam.

The major cause of trouble in routine operation of the field is the fact that it can be operated from day to day with relatively little attention. Changes in the field are slow, but can add up to major problems. In this connection, three problems became evident and are outlined in the order seen.

1. Possible depletion of plant nutrients. In the spring two black streaks of dead foliage showed in the field. Fertilizer addition and replanting the dead area corrected this condition.

2. Erosion. The 40-acre field is bowl-shaped. The sides of the bowl are not

FIGURE 8.—General view of irrigation field.

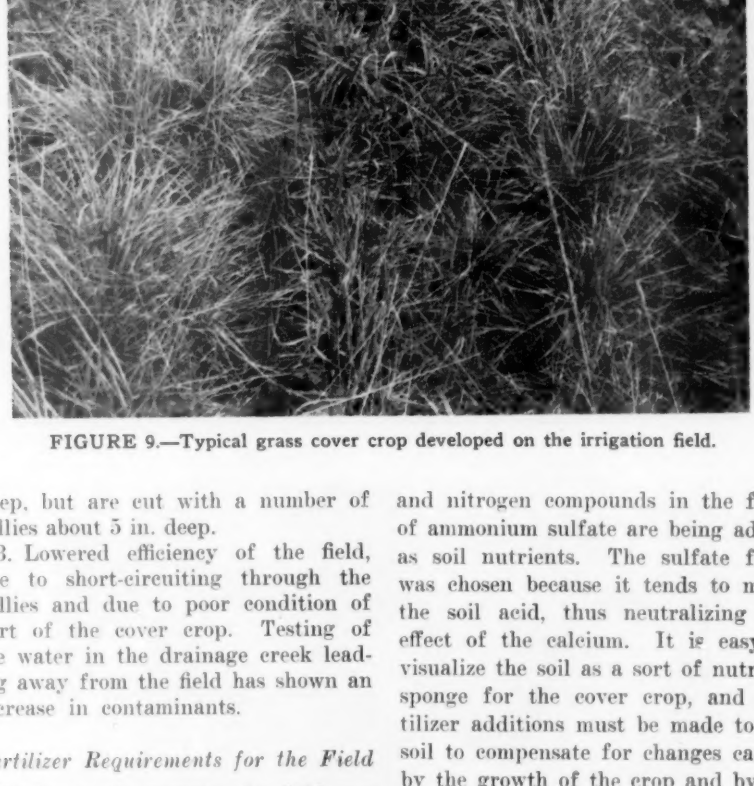

FIGURE 9.—Typical grass cover crop developed on the irrigation field.

steep, but are cut with a number of gullies about 5 in. deep.

3. Lowered efficiency of the field, due to short-circuiting through the gullies and due to poor condition of part of the cover crop. Testing of the water in the drainage creek leading away from the field has shown an increase in contaminants.

Fertilizer Requirements for the Field

Early in the summer the field was divided into 30 test areas for soil sampling. Analysis of the soil samples indicated a marked deficiency of potassium and available phosphate in the soil. In addition, the soil has become more alkaline. The calcium in the waste remains in the soil after the organic portion is destroyed, thus explaining the tendency of the soil to become more alkaline. This alkalinity decreases the availability of phosphate compounds for the plants. The potassium compounds are apparently being leeched out of the soil.

At the present time specific amounts of phosphate, potassium compounds, and nitrogen compounds in the form of ammonium sulfate are being added as soil nutrients. The sulfate form was chosen because it tends to make the soil acid, thus neutralizing the effect of the calcium. It is easy to visualize the soil as a sort of nutrient sponge for the cover crop, and fertilizer additions must be made to the soil to compensate for changes caused by the growth of the crop and by the effect of spraying.

Summary

Spray irrigation seems particularly suited for nontoxic, high BOD, water soluble organic wastes. In retrospect, the following steps are recommended for a similar problem:

1. Study the separate process wastes chemically, determining toxicity and neutralization requirements.

2. In a greenhouse program, determine suitable plants and quantity of waste which can be tolerated for a given surface area. These tests should be made on the individual and sepa-

rate process wastes, and on a blended composite of those wastes which appear suitable.

3. Irrigate a small plot to confirm greenhouse tests.

4. Design spray field and handling system in cooperation with a soil conservationist and an agronomist. These can be contacted through the local county agent.

5. Install the system, operate it, and keep up with changes in soils and streams.

The application of spray irrigation has resulted in a real improvement in the stream pollution problem, and has proved to be a useful and practical means for industrial waste disposal at the Wrigley wood distillation plant.

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3. Burk, A. A., and Schroeder, W. C., "Determination of Tannin Substances in Boiler Water." *Ind. and Eng. Chem.*, Anal. Ed., **14**, 456 (1944).
4. McElvan, S. M., "The Characterization of Organic Compounds." The Macmillan Co., New York (1946).

NORTHCUTT NAMED BDSA ADVISOR

John W. Northcutt, Assistant Vice-President of the Rockwell Manufacturing Company, Pittsburgh, was recently named an Advisor to the Director of the Water and Sewerage Industry and Utilities Division, Business and Defense Services, U. S. Department of Commerce. Mr. Northcutt comes to BDSA for a temporary tour without compensation from the Government. He becomes available for membership in the National Defense Executive Reserve which would staff the operation of a production agency in event of emergency.

Stream Pollution

AQUATIC LIFE WATER QUALITY CRITERIA

Third Progress Report *

AQUATIC LIFE ADVISORY COMMITTEE OF THE OHIO RIVER VALLEY WATER SANITATION COMMISSION

Cincinnati, Ohio

FOREWORD AND ACKNOWLEDGMENT

Since 1952 an eminent group of biologists and fisheries scientists has been serving as an Aquatic Life Advisory Committee to the Ohio River Valley Water Sanitation Commission. Their task has been to define what constitutes "waters . . . capable of maintaining fish and other aquatic life." This statement finds expression in the Ohio Valley compact for pollution control ratified by the states of Illinois, Indiana, Ohio, Pennsylvania, New York, Virginia, West Virginia, and Kentucky.

This report is the third to be made by the committee. The first (THIS JOURNAL, **27**, 3, 321 [Mar. 1955]) dealt with dissolved-oxygen requirements, hydrogen-ion concentration, and criteria for judging toxicity of wastes by bio-assay. The second report (THIS JOURNAL, **28**, 5, 678 [May 1956]) set forth findings with regard to temperature, dissolved solids, settleable solids, chloride ion, fluoride ion, and color; also included were supplementary data on the validity of dissolved-oxygen requirements.

In the current report the committee discusses radioactivity and aquatic life, detergents, cyanides, phenolic compounds, iron, and manganese.

The committee includes the following members:

Lloyd L. Smith, Jr., Department of Entomology and Economic Zoology, University of Minnesota, *Chairman*

Bertil G. Anderson, Head, Department of Zoology and Entomology, The Pennsylvania State University

James B. Lackey, Department of Civil Engineering, University of Florida

Edward Schneberger, Superintendent, Fish Management Division, Wisconsin Conservation Commission

Clarence M. Tarzwell, Chief of Aquatic Biology, Robert A. Taft Sanitary Engineering Center, USPHS

Walter A. Chipman, Chief, Special Shellfishery Investigations, U. S. Fish and Wildlife Service

O. Lloyd Meehean, Assistant to the Director, U. S. Fish and Wildlife Service

William A. Spoor, Department of Zoology, University of Cincinnati.

Serving as secretary to the committee is William L. Klein, chemist-biologist on the Commission staff.

In making this report available for publication, the Commission wishes to acknowledge its appreciation of the valued contributions made by its Aquatic Life Advisory Committee.

EDWARD J. CLEARY
Executive Director and
Chief Engineer, ORSANCO

The Aquatic Life Advisory Committee has considered a number of matters since the presentation of the last progress report. Among them have been a review of plans for the ORSANCO aquatic life resources project, and

* Submitted to the Ohio River Valley Water Sanitation Commission, June 18, 1959.

TABLE I.—Effect of Iron Concentration and pH on Survival Time of Sticklebacks

pH	Iron (mg/l)	Survival Time
4.6	1.5	3 days
4.4	2.0	2 days
4.2	3.0	1 day
3.8	7.0	6 hr
3.4	20.0	3 hr

water-quality criteria for iron, manganese, phenol, cyanides, radioactive wastes, and detergents. The results of these considerations are as follows:

Criteria for Iron and Manganese

The heavy metals are much more toxic to fishes in soft water than in hard water. They are also more toxic at the lower pH values but are considerably less toxic in the presence of certain metallic salts which may exercise an antagonistic action. Temperature and dissolved oxygen also influence the toxic effects of these materials, the fishes being more adversely affected when the temperature is high and/or the dissolved oxygen is at lower levels. Duration of exposure is also important. While some metal cations are antagonistic to other heavy metals, others are synergistic, with mixed solutions of their salts being more toxic to fishes than simple solutions of corresponding concentrations. For example, it has been found that mixtures of nickel and zinc, copper and zinc, and copper and cadmium are much more toxic than equal concentrations of their simple salts.

Solutions of chlorides, nitrates, or sulfates of iron are acidic as a result of partial hydrolysis. When one of these iron salts is added to an alkaline natural water, precipitation of a nearly insoluble iron hydroxide will occur. Very little of the salt will remain in solution until enough has been added to neutralize the natural alkalinity of the water and to decrease the pH sufficiently so that further precipitation does not occur. This amount can vary with the pH of the water and the amount of CO_2 in solution. Further, lethal levels are not the same for all fishes, since some are much more sensitive than others.

Jones (1) reports that sticklebacks held in a tap-water solution of $FeCl_3$ which at pH 5.0 had 1 mg/l of iron in solution lived as long as controls held in soft tap water. At lower pH values the fish died in shorter times. The average survival times are shown in Table I.

Since there was no significant difference between mortality rates in these solutions and in solutions of HCl with corresponding pH values, it was concluded that the toxicity of the $FeCl_3$ solutions was due mainly or entirely to their acidity and that the relative toxicity of ferric ions could not be evaluated. A similar result was reported for $FeSO_4$.

While the formation of precipitates usually results in the inactivation of toxic metals, it has been stated that precipitates of $Fe(OH)_3$ clog the gills of fish and interfere with their respiration. It may also smother fish eggs (2)(3).

While iron has been investigated by a number of workers, very little is known definitely about the toxicity of iron salts. Some investigators have reported that about 1 mg/l or even lower concentrations of iron can be lethal, but others have been unable to demonstrate its toxicity. Jones (1) reported that at favorable pH levels iron salts were not significantly harmful. Ellis (4) found that 100 mg/l of $FeCl_3$ in hard water at pH 5.5 and 10 mg/l in very soft water at pH 5.0 did not kill goldfish in 4 days; whereas 100 mg/l in soft water at pH 3.4 proved fatal in 80 min. An HCl solution at pH 3.5 had approximately the same lethal effect. He reported that 1,000 mg/l of the $FeSO_4$ in hard water at pH 6.4 was lethal to goldfish in 2 to 10 hr.

Jones (1) has shown that manganese

nitrate can be toxic to fish in soft water at concentrations of 50 mg/l of manganese. Sticklebacks were killed in about 24 hr by 300 mg/l. Oshima (5) and Iwao (6) reported the toxicity of $MnCl_2$ and $MnSO_4$ to be slight, with lethal concentration limits being near 5,500 and 3,400 mg/l, respectively. Manganese does not precipitate out to any extent as $Mn(OH)_2$ at pH values below 7.5. Thus, it does not have a smothering effect. The permanganates are much more toxic than the manganous salts; the former killed fish in 8 to 18 hr (4)(5)(6) at concentrations of from 2.2 to 4.1 mg/l of manganese.

In general, manganese is undesirable in water supplies. Because it gives color and precipitates in water pipes at lower concentrations than those at which it is toxic to fishes, toxicity will not usually be paramount in establishing maximum allowable concentrations. Where water supplies are not important and fishing is the main consideration, some limits should be established. Because results obtained under different experimental conditions vary approximately a hundredfold, it is not considered feasible to establish numerical standards at this time. This situation also exists with regard to the iron salts.

Since a great many factors such as temperature, dissolved oxygen, carbon dioxide, alkalinity, hardness, and salts of other metals and materials dissolved in the water influence or largely determine the toxicity of iron and manganese, it is apparent that the character of a receiving water is of major importance. Because the content of our natural waters varies widely, especially those receiving industrial wastes, and since these materials never occur alone but are usually in complex wastes, the setting of allowable levels for iron and manganese in mg/l is unrealistic, of little practical value, and can be very misleading. It is recommended, therefore, that the toxicity of wastes containing these materials be determined by bio-assay using the waste which will be added to the stream and dilution water from the stream at the point at which the waste is to be added. These determinations will give information on the amount of the waste which can be added safely to that particular stream at that particular point, and effluent or stream standards can be set accordingly.

Criteria for Cyanide

As has been pointed out in the previous section, the setting of maximum permissible concentrations for an ion or a material in the receiving waters of a region is a difficult and not always desirable procedure. The maximum permissible concentration will be the concentration which is not harmful to aquatic life under continuous exposure in those waters in which the substance is most toxic. This criterion means that if these standards are used for a state or region, the majority of the industries must treat their wastes far in excess of requirements for safety in their receiving streams. This situation will be especially true for cyanide and ammonia, the dissociation of which is a function of pH and the metals, and the solubility of which is influenced by pH and hardness. Further, with cyanide the problem is complicated by the fact that there are many cyanides with widely varying toxicity. Some are relatively non-toxic, some approach HCN in toxicity, while others are subject to photodecomposition or dissociate under certain conditions to become almost as toxic as HCN. Since it is customary to report cyanides as the CN^- ion, this chemical measure can be very misleading as an indication of toxicity.

It is, therefore, apparent that the establishment of cyanide standards expressed as mg/l of CN^- is not always a desirable procedure for a large region in which there is considerable variation of the water-quality characteristics which influence toxicity, such

as temperature, dissolved oxygen, pH, total alkalinity, hardness, and other dissolved materials. If it is considered essential to establish such criteria, the following facts should be noted when the criteria are set up.

Available information on the relative tolerance of different species of fish to free cyanide in water is very incomplete. There is no evidence that the warm-water fishes of the Ohio Valley are all significantly more resistant to cyanide than are certain species of trout, which have been more thoroughly investigated than other kinds of fishes. The apparent evidence that some warm-water fish species are more resistant to cyanide than trout may well be attributable in large degree to defects of the experimental methods employed and to the high resistance of the test animals.

A number of environmental factors markedly influence the resistance of fish to free cyanide. It has been shown, for example, that in water with a reduced dissolved-oxygen content, such as often occurs in polluted streams, trout are decidedly more susceptible to cyanide than they are in well-oxygenated water. The pH of dilute cyanide solutions, which determines the proportion of cyanide-ion concentration to the concentration of undissociated HCN, also influences the toxicity. Undissociated HCN has been shown to be more harmful to fish than cyanide ions in equivalent concentration. Temperature has a marked influence upon the lethality of cyanide to fish, similar to its influence on the rate of respiratory metabolism. The rate of lethal action increases about two- to three-fold with a rise in temperature of 10°C over a wide range of temperatures. Generally speaking, maximum susceptibility to cyanide may be expected to occur at relatively high summer temperatures and at times when dissolved-oxygen concentrations and pH values (which may be influenced by various pollutants) are minimal.

Toxicity Tests

At the usual pH values of natural surface waters, most of the free cyanide present in dilute cyanide solutions occurs in the form of undissociated hydrocyanic acid which is volatile. For this reason, and perhaps for other reasons, such as possible detoxification of considerable amounts of cyanide by test animals, the toxicity of standing cyanide solutions in experimental aquaria is not constant, but declines markedly with time. If the test solutions are not renewed frequently or continually (by means of constant-flow apparatus), the results of toxicity tests do not accurately indicate maximum concentrations of cyanide which can be tolerated by fish for extended periods, even when the tests are quite prolonged. Artificial aeration of test solutions may greatly increase the rate of loss of cyanide. Most experiments on the toxicity of cyanides to fish which are reported in the literature have been of brief duration, or are more or less defective in some respect.

Experiments of relatively long duration on the toxicity of potassium cyanide to rainbow trout with continual renewal of test solutions have been reported by Herbert (7) and by Herbert and Merkens (8). These studies were carefully planned, and the results are deemed reliable. The lowest concentration of cyanide tested was 0.07 mg/l CN^-. At this concentration, a temperature of 17.5°C, and pH of from 7.4 to 8.0, the mean survival (overturning) time of yearling rainbow trout was reported to be 74 hr. There was no indication that 0.07 mg/l CN^- is the minimum fatal concentration, but on the contrary, the data suggest lethality of considerably lower concentrations after more prolonged exposure. Within the range of cyanide concentrations from 0.07 to 0.25 mg/l, a straight-line relationship between the logarithm of survival time and the logarithm of cyanide concentration was noted. It was pointed out (7) that

the equation representing this relationship "does not imply the existence of a threshold concentration at all. There are reasons for supposing that a toxic concentration threshold above 0.023 [mg/l] CN^-, under the conditions of these experiments, actually may well exist, but apparently it would be far below 0.07 [mg/l]. At concentrations of about 0.09 [mg/l] CN^- (0.08–0.1 [mg/l]) the mean survival time of the trout was only about 43 hours."

Much earlier, Karsten (9) reported that all of eight 6-in. brook trout died within 130 to 136 hr at a cyanide concentration of 0.05 mg/l in continually renewed (flowing) experimental solutions (in 2 tests); whereas all of six brook trout lived for 27 days at a concentration of 0.02 mg/l CN^-. Two fish turned over in 22 to 80 hr when exposed to 0.07 mg/l CN^-. The temperature and pH of the test solutions were not reported, but these results agree quite well with those of Herbert and Merkens.

Complex Cyanides

Cyanide can occur in industrial wastes in the form of complex cyanides, some of which have been shown to be much less toxic than free cyanide in solutions with equivalent cyanide content. Some metals, such as nickel, complex readily with cyanide in very dilute solutions of mixed salts whereas others do not. The complex metallocyanide ions vary widely in their stability. The zinc-cyanide complex, for example, appears to be almost completely dissociated in very dilute solutions which have been found to be even more toxic than comparable solutions of alkali cyanides without zinc (apparently because there is synergistic action). The nickel-cyanide complex, on the other hand, is relatively stable and can be present in water in high concentration (e.g., over 100 mg/l as CN^-) without apparent harm to fish life if the water is fairly alkaline. Even the relatively stable complexes, however, may be largely decomposed under some conditions. In acidic waters the toxicity of the nickel-cyanide complex approaches that of free cyanide with the degree of its dissociation and toxicity varying greatly with pH; and the ferro- and ferri-cyanide complexes which are highly stable (i.e., have low dissociation constants) have been shown to be largely decomposed under the influence of sunlight. It is noteworthy, also, that the toxic forms of cyanide in solutions of complex cyanides can always be distinguished readily from the non-toxic forms and measured accurately by chemical means.

Maximum Permissible Concentration

In the absence of any concrete evidence showing that all important fish species occurring in the Ohio Basin can tolerate significantly higher concentrations of cyanide in these waters than were tolerated by rainbow and brook trout in the experiments mentioned, permissible concentrations of cyanide in these waters should be based on the reliable tolerance data obtained with these species of trout. Since concentrations of free cyanide as low as 0.05 to 0.07 mg/l CN^- have been shown to be fatal to the trout in about 1 to 6 days, these and higher concentrations may not be deemed safe if they are maintained indefinitely or for long periods of time. Furthermore, in waters with varying degrees of pollution fishes may be exposed to cyanide under more adverse environmental conditions (with respect to dissolved-oxygen concentration, temperature, pH, the presence of synergistic materials, etc.) than those which were maintained in the course of the experiments with trout. In order to estimate safe or permissible concentrations of cyanide, therefore, a margin of safety must be provided which allows for greater susceptibility of fishes to cyanide under the more adverse conditions, as well as for exposure periods which may be

longer than those used in experiments of limited duration.

It is therefore recommended that concentrations of free cyanide in excess of 0.025 mg/l be considered unsafe for fish life in the waters of the Ohio River.

Serious practical objections may be raised to the adoption of 0.025 mg/l CN^- as a limit of permissible cyanide concentration because maximum concentrations in receiving waters are not likely to persist for long periods of time, and the average concentrations may ordinarily be well below the maximum; further because areas where contamination of the water is maximal may not be frequented by the most sensitive fishes. It is believed, however, that until information contrary to the facts outlined above becomes available, numerical criteria should be established at 0.025 mg/l.

These conclusions refer specifically to free cyanide concentrations. Strict application to all complex cyanides of permissible concentration limits based on the toxicity of free cyanide, would be somewhat arbitrary and not always easily justifiable. On the other hand, it is not feasible to set up different permissible concentration limits for cyanide in all its possible combinations and under all the conditions (with respect to pH, etc.) under which it may occur in polluted waters. If any permissible limits of cyanide concentration are to be adopted for general application, therefore, they must be deemed applicable to cyanide in all forms or combinations, partly on the grounds that the cyanide in non-toxic, complex metallo-cyanide ions may, under some conditions, be largely or entirely liberated in highly toxic form. Only when there is assurance that liberation of free cyanide in excessive amounts would not occur in any particular instance, should the general restrictions be relaxed.

The best procedure is to conduct bio-assays to determine directly how much of a cyanide-bearing waste can be added to a particular stream at a particular point. Where compounds subject to photodecomposition are present, bio-assays should be made under full sunlight conditions.

Criteria for Phenolic Compounds

The recommendations of the Committee for allowable concentrations of phenolic compounds are based on several considerations. These are: the broad implications of the term "phenolic wastes"; the variety of adverse effects of phenolic compounds on aquatic life; the indications that species vary in susceptibility to phenols; the relationships between environmental variables and the toxicity of phenolic compounds; and the present state of the literature on the subject.

The number of "phenolic substances" occurring in wastes requires that the criterion be set for phenolic compounds as a group, rather than for phenol itself or for any one of the substances associated with it in wastes. A criterion based on phenol alone would be misleading because it is by no means the most toxic of phenolic compounds. Mixed phenolic wastes are generally much more toxic than pure phenol (Table II). Further, the phenolic components of wastes are not constant in type or quantity but vary according to the processes giving rise to the wastes. The criterion should therefore apply to all.

Not infrequently the toxicity of a waste, the "phenol" content alone of which is measured, may be due to non-phenolic substances (e.g., cyanide).

Although the oxidation of phenolic compounds by natural agencies tends to reduce the dissolved-oxygen content of water, the oxygen-depleting effects need not be taken into account in establishing this criterion because the concentrations of phenolic substances required to lessen the dissolved oxygen by a significant amount are consider-

TABLE II.—Representative Concentrations of Phenolic Substances Having Adverse Effects on Fresh-water Fishes*

Compound or Waste	Concentrations Having Harmful or Lethal Effects (mg/l)	Concentrations Affecting Taste and Odor (mg/l)	Fish Tested
Pure compounds			
phenol	5–20	15–25	Trout, carp, tench, chub, eel, minnow, perch, bluegill, pike, goldfish
cresols	10–15	10	Tench, carp, eel, trout, minnow
xylenols	5–10	1–5	Roach, perch, carp
pyrocatechol	5–15	2.5	Perch, carp, roach
resorcinol	35	—	Carp, roach
hydroquinone	0.2	—	Perch, stickleback, carp, goldfish
pyrogallol	20–50	20–30	Roach, carp
p-quinone	0.2–1.0	0.5	Carp, tench, roach
pyridine	160–200	5	Roach, carp
naphthalene	—	1	Roach
alpha naphthol	2–4	0.5	Roach, carp
quinoline	10	0.5–1.0	Roach, carp
chlorophenol	10–20	0.1	—
Mixed phenolic wastes			
coal-coking wastes	3–5	0.02–0.1	Fresh-water fish
coal-tar wastes	3	0.1	Fresh-water fish
gas wastes	0.5–5	—	Minnow, trout
phenols in polluted river	0.079	0.02–0.15	Minnows
	0.285	—	Fresh-water fish absent at this conc.
sewage containing phenols	3–5	0.1	Fresh-water fish

* Data on compounds other than phenol largely from Ref. 11.

ably greater than those permissible on other grounds.

Taste and Odor Considerations

Even in low concentrations, some phenolic substances affect the taste and odor of fish, either directly or by affecting the fish-food organisms (Table II). Mixed wastes seem to be especially troublesome in this respect. According to one report, mixed wastes which contained from 0.02 to 0.03 mg/l phenols affected the taste of river fish within an hour. This effect is reversible since fish lose the phenolic taste and odor when transferred to clean water.

In higher concentrations, phenolic compounds may cause irritation, loss of balance, paralysis, and death of fish and other aquatic organisms (Table II). The mixed phenolic wastes appear to be more toxic than pure substances in general, although hydroquinone and *p*-quinone are highly toxic in pure solution. The concentrations required to cause death, however, are usually so much higher than those affecting taste and odor that they have not been employed as the basis for the criterion.

Low concentrations of phenolic substances may cause fish to avoid polluted areas. According to the extremely limited information available, the phenolic concentrations likely to have this effect are much lower than those causing death. Kalabina (10) found an abundant and diversified fish population in a phenol-contaminated river bearing 0.02 mg/l "phenol," but found no fish in parts of the river bearing 0.28 mg/l. Kalabina concluded that fish would not inhabit streams contaminated with phenolic wastes in excess of 0.2 mg/l phenol. As the fish population becomes depleted as effectively by emigration as

by death, it would seem that here, as with the taste and odor problem, the criterion should be related to concentrations that fish will avoid, rather than to those causing death. The situation is complicated by the fact that some fish seem to be unable to detect low concentrations of phenol (pure phenol in this case) in time to avoid being overcome by it. This problem of avoidance of phenol-contaminated areas requires much more research.

Aquatic invertebrates in general seem to be slightly less susceptible than fish to the toxic effects of phenols, although there are some exceptions. The criterion should therefore be based on the data available for fish. Fish vary in their sensitivity to phenols, with trout and perch appearing to be more susceptible than carp, goldfish, and bluegills.

Phenolic compounds are less toxic in hard than in soft waters and at low than at high temperatures. The taste and odor problem, however, may become more acute at low temperatures where oxidation and volatilization become less effective in removing phenolic compounds. A given concentration of phenolic substance becomes more toxic as the dissolved-oxygen supply diminishes. This relationship is related to the respiratory requirements of the fish, rather than to those of the microorganisms that destroy phenols.

Research Needs

The Committee wishes to point out as a final consideration that the literature on phenols is poorly applicable to the fundamental problem of establishing a concentration of phenolic substances that will permit the maintenance of a well-rounded and harvestable fish population. Most of the literature pertains to acute toxicity in which the end point is paralysis or death. Very little of it deals with the effects, either upon individual fish or upon the population as a whole, or chronic exposure to concentrations not acutely lethal. The literature deals chiefly with the toxicity of pure phenolic compounds and, furthermore, there seems to have been no systematic study of the effects of phenolic compounds upon different stages in the life histories of fish. Most of the data pertain to adults, which may or may not be as sensitive as younger stages. The scarcity of information on the concentrations that will cause fish to avoid a body of water has been mentioned above. There is very little useful information on American fishes since most of the literature has originated in Europe.

The Committee, therefore, suggests that research be undertaken to provide more information on the concentrations of mixed phenolic wastes at which a well-rounded, harvestable population of North American fishes can maintain itself. Such research would entail more emphasis on (*a*) the effects of phenols upon the egg and fry stages, (*b*) the relationship between phenol concentration and the taste and odor of fish (*c*) the chronic effects of low concentrations of phenol, and (*d*) the concentrations that fish will avoid.

Maximum Permissible Concentration

In view of the considerations outlined above, the Committee recommends that for the maintenance of a well balanced, harvestable fish population the total concentration of phenolic substances after the addition of a waste to the receiving water be not higher than 0.05 mg/l.

This figure is the Committee's estimate of a concentration of phenolic compounds which in most mixed phenolic wastes seems unlikely to impart objectionable phenolic tastes and odors to fish, since taste and odor are affected at concentrations generally much lower than those required to kill fish. Further research may indicate the desirability of a low concentration, inasmuch as taste-and-odor-affecting con-

centrations as low as 0.02 mg/l phenol have been reported (see Table II).

Radioactivity and Aquatic Life

Development of uses of atomic energy with concurrent expansion or establishment of industrial plants concerned with these uses has created the need for consideration of disposal of wastes containing radioactive materials. To a great extent streams and rivers offer a convenient means of removal of such waste products. Excessive discharge of radioactive wastes into streams would prevent their use for domestic and industrial water supply, for agricultural purposes, and for fishing and recreation. It is important to consider what levels of contamination may be considered permissible for all multiple water uses. The present purpose is to discuss the ways in which pollution of streams with radioactive wastes might affect aquatic life and to report the present state of knowledge of levels of total radioactivity and of individual radionuclides above which organisms or populations of organisms of streams may be expected to be adversely affected.

The Stream Pollution Problem

Stream pollution problems of atomic-energy industries are essentially the same as those confronting many other industries. The stream environment may be altered by temperature changes, addition of toxic chemicals, or entry of radioactive materials. When considering the possible effects of pollution from such installations on aquatic life, damage caused by radiation from radioisotopes released to the stream is the primary concern. The presence of toxic chemicals in the effluent or release of wastes of high temperature, however, may also be responsible for adverse effects.

The hazardous nature of the wastes depends to a great extent on specific radioactive elements present. Many radionuclides are isotopes of elements of biological importance and enter into many biochemical processes within the organism. Certain radionuclides are accumulated by aquatic life to very high levels. It is, therefore, important to consider the radioactive components of the wastes entering a stream as well as the total amount of radioactivity.

In instances where there is continuous discharge of atomic materials into streams, the concentration of radioactivity in the water is dependent not only on factors of dilution but also on the rate of physical decay of the contained radioisotopes. In the case of pollution with radioisotopes of relatively short half-life, the time required to reduce the radioactivity to half its original concentration is short enough so that significant concentrations are maintained only close to the point of entry. Not only is there an equilibrium established between the rate of entry and the rate of loss from the water, but other equilibria are formed between the radioactivity levels of the water, bottom sediments, and aquatic life.

If there is a sudden non-continuous and relatively high level of contamination within a limited area, radiation hazards and damage to aquatic populations are possible. Although this catastrophic situation is unlikely where radiation hazard control is properly exercised, the possibility of occurrence should be recognized. In this type of pollution, the rates of uptake, accumulation, and biological loss assume considerable importance.

Environmental Contamination

Pollution of streams with radioactive wastes is an environmental contamination problem. Attention should be brought to the fact that there is no loss of radioactivity from the environment except from physical decay of the radioisotopes concerned, although there may be dispersion and dilution of the radioactive materials. There is also

a large loss from the water by precipitation and settling, adsorption of radionuclides on suspended particles or bottom materials, and from uptake by aquatic life. Bottom algae, bacteria, and other organisms in the mud apparently constitute a great reservoir for the retention of added radionuclides. These materials are slowly returned to the water and moved downstream with great dilution. As the biota in the mud carries out the degradation of the organic matter there, considerable recycling must occur. The chemical components are transferred from one organism to another, and soluble salts, together with organisms, are gradually lost downstream along with their radioactivity. Experience has shown that relatively large amounts of radioactive wastes may be added to a stream without greatly increasing the radioactivity levels of the water. The extent of this great absorptive capacity of the bottom materials is evidenced from the fact that relatively low levels of radioactivity in the water are found even after the addition of radioactive materials over a period of years.

Great care is exercised in monitoring and releasing radioactive wastes to surface waters by atomic-energy installations. Only low level radioactivity is permitted to be discharged and this release only in amounts which would result in stream levels well below those considered as the maximum permissible concentration (MPC) for water according to the recommendations of the International Committee on Radiation Protection (12). The permissible levels of gross radioactivity from alpha emitters and for beta and gamma emitters are the same, 10^{-7} μc/ml above natural background. Because aquatic organisms have the ability to concentrate certain radionuclides, there is considerable question as to whether or not these levels may be permissible insofar as aquatic life is concerned. Foster (13) makes the statement, based on observations of the accumulation of radiophosphorus by organisms of the Columbia River and on other studies, that "if radiophosphorus were allowed to reach the maximum level permitted for drinking water, organisms living in the water would suffer radiation damage and the fish would be unsafe for human food."

Concentration Factors

To ascertain safe levels for aquatic life it is necessary to know concentration factors for certain critical radioisotopes that may be added to aquatic environments, the organs or tissues which serve as sites for accumulation, the stages in the life histories which are most sensitive to radiation, and at what radiation levels damage may be expected to occur.

The accumulation of a radioisotope by an organism is related in part to the degree that the particular element is concentrated within the organism. It is also related to the specific activity of the isotope in the environment, i.e., the ratio of the number of radioactive atoms to the total atoms of the same element which are present. The rate of incorporation depends on the dynamic processes of change of elements within the organism.

Chemical exchange of radioactive atoms for other atoms in different chemical compounds on or within an organism may allow for uptake of radioactivity. Accumulation may also depend on the abundance of other chemical elements present in the organism or environment. For instance, there appears to be a common metabolic pool of potassium and cesium and the accumulation of radiocesium is dependent in part on the amount of potassium available (14).

Aside from the elemental composition of the organism, there are physical factors such as adsorption and exchange that contribute to accumulation of radioelements. The adsorption of elements or particles to surfaces may be an important factor, particularly

where surface areas are extremely great, as they are in the case of microorganisms and plankton.

The mode of entry of radioactive materials into organisms must be considered. Photosynthetic plants, the primary concentrators, take chemical elements directly from the water. Although the higher animal forms depend on the primary concentrators for their source of energy, these animals may or may not be dependent on the lower forms for many elements. Some elements may enter the bodies of the higher forms directly from the water, while others are supplied from the lower levels through the intake of food. This dependence on food organisms results in the establishment of food chains, or webs. The dependence of one animal on others or on aquatic plants is not static and varies with season of the year, stage in the life cycle, changes in availability, etc.

It has been stated that accumulation of radioactivity by aquatic organisms appears to follow a pattern in which accumulation is greatest in the aquatic plants, is next highest in the small animals which feed on plants, and is progressively less in animals of the food chain leading to the higher carnivorous fishes. It is also related to the rate of physical decay of the radioisotope and the time required for passage through the food chain. Differences in the pattern can arise from selective uptake of elements by organisms.

Our knowledge of the ability of various species of an aquatic community to concentrate radioactive materials is meager. Laboratory studies may be useful but they are often of short duration and do not include many of the factors existing in the natural environment. Observations made on accumulations of radioactivity in natural waters where there is known pollution are of greater value. There have been several field studies of pollution made in both fresh and marine areas with atomic materials. The studies made on the Columbia River, White Oak Lake, and the Mohawk River are particularly important. In each of these locations the type of pollution, the environment, and the biota are different.

TABLE III.—Maximum Gross Beta Radioactivity in Organisms in the Columbia River and Concentration Factors

Sample	Beta Activity (10^{-6} μc/g)*	Concentration Factor Compared with Water
Water	19	1
Plankton	80,000	4,210
Filamentous algae	13,000	684
Bottom animals	10,000	526
Juvenile forage fish (shiners)	9,000	474
Adult food fish (suckers)		
bone	5,000	263
muscle	1,100	58
Adult game fish (bass)		
bone	3,500	184
muscle	450	24

* Millionths of a microcurie per gram of water or of fresh tissue.

The plutonium production plant at Hanford makes use of river water to cool the reactors. In passing through the reactors certain elements in the water become radioactive from neutron bombardment. For the most part, the radionuclides in the effluent are beta emitters of relatively short half-life. Omitting those radionuclides which have half-lives shorter than 10 hr, there are measurable amounts of Na^{24}, Cr^{51}, Cu^{64}, P^{32}, As^{76}, and also rare earths (15). The reactor effluent, in addition to being mildly radioactive, has a high temperature and contains chromate and chlorine which are toxic to aquatic organisms (16).

In studies of the Columbia River made by the U. S. Public Health Service (17)(18) the greatest accumulation of gross beta radioactivity was observed in the plankton. There was a decrease in the concentration factors in organisms through the food chain leading to the higher fishes. The maximum concentrations found in different types of organisms from stations just below the plant and the concentration factors over water are listed in Table III.

Effect of Radionuclide Accumulation in Organisms

According to Davis *et al.* (19) the radioactivity of the fish of the Columbia River in that area was predominantly from P^{32}. They contained small amounts of Na^{24} and traces of longer lived elements. The proportion of P^{32} to shorter lived isotopes was less in insect larvae, algae, and plankton. This may have been in part the result of selective uptake of certain elements by different species, but was likely due to the decay of shorter lived isotopes during the time required for passage through the food chain.

Although the aquatic organisms are concentrating radioisotopes (particularly P^{32}) discharged into the Columbia River, there is no evidence in the surveys made which indicates any deleterious effects on the populations. However, Davis *et al.* (20) state:

> Radioactive materials deposited in the flesh of food fish of the Columbia River constitute a potential radiation hazard. Substantial quantities of Rocky Mountain whitefish (*Prosopium williamsoni*), smallmouth bass (*Micropterus salmoides*), and steelhead trout (*Salmo gairdnerii*) are caught in this vicinity by sportsmen. The whitefish is caught in particularly large numbers during the winter season. During the winter of 1952 approximately half of the whitefish sampled from Priest Rapids, a popular sportfishing area located upstream from the Hanford operations, had radioactivity density levels equal to or greater than those occurring in fish caught immediately below the reactor areas. An activity density of 2.2×10^{-3} μc/g in the muscle of one specimen from Priest Rapids represented the maximum value found in flesh of adult game fish sampled during the year.

The accumulation of radioactivity by aquatic life in White Oak Lake, which received radioactive wastes from the Oak Ridge National Laboratory, was studied over a 3-year period (21) (22). The composition of the wastes varied from day to day, but there were relatively large amounts of Sr^{89}, Sr^{90}–Y^{90}, Cs^{137}, Ce^{144}, Ru^{106}, and other fission products present at all times. In addition, there were relatively large amounts of other radionuclides, such as P^{32} and Co^{60}, present on various occasions (15). The lake also received other chemical wastes and sewage.

Although the amount of radioactivity of the water differed in various parts of the lake, it was generally rather high. One observation is reported (21) of a gross beta activity of 7.3×10^{-3} μc/g, and Krumholz indicates (22) that an average concentration of radioactivity in the water of 10^{-3} μc/ml would not be unreasonable. A lower average of approximately 4.5×10^{-5} μc/ml was given in the earlier report (21).

Each of the organisms in the entire food chain leading to the higher fishes had concentrated radiomaterials in its tissues. Some selectively concentrated one radioelement and some concentrated another. Most of the zooplankton had concentrated radiophosphorus more than any other radioelement. Others included strontium, ruthenium, cesium, and cerium. The filamentous algae contained rare earth radionuclides almost equal to radiophosphorus. All organisms had accumulated radiostrontium.

Fish were found to have concentrated radioactivity to a marked degree. The total radioactivity of a 7-in. black crappie was noted to be 1 μc. Bluegills had slightly less. Radioactivity in the bone was due principally to Sr^{90}, which accounted for 80 per cent; P^{32} contributed 10 per cent; rare earth nuclides, 5 per cent; and others, 5 per cent. The highest radioactivity of the soft tissues (which exceeded that of the bone in bluegills) was in the liver. Muscle tissue has lowest radioactivity. In the soft tissues the accumulated radioactivity was due to Cs^{137}, together with smaller amounts of radioruthenium, radioactive cerium-praseodymium, radioniobium, and radiozirconium. The amounts of Cs^{137} ranged from 50 to 90 per cent. The

greatest amount of ruthenium which was detected composed about 10 per cent of the total. None of the other elements ever contributed more than about 3 per cent.

The fishes in White Oak Lake contained high concentrations of Sr^{90} and Cs^{137}, although the greater part of the radioactivity of their food organisms was due to an accumulation of P^{32}. The fish skeletons derived 80 per cent of their radioactivity from Sr^{90} although only a relatively small amount of radioactivity in the plankton organisms emanated from that radioisotope. Similar examples of selective accumulation of specific radionuclides are quite well known. Marine fish fed mixed fission products in which nearly all the gross radioactivity was due to Ce^{144}–Pr^{144} had a high radioactivity from a great accumulation of Sr^{89} and Sr^{90} in the bone and an accumulation of Cs^{137} and other radionuclides in the soft tissues (23).

The study of White Oak Lake was of too short duration to demonstrate definite changes in the biota. However, some changes which may have been the result of irradiation were observed to be taking place in segments of the fish population. It was noted that fish in White Oak Lake grew more slowly than fish of the same species in nearby reservoirs and also that they had shorter life spans. These are two of the classical effects of exposure of animals to radiation. It was also observed that two species of fish, the white crappie and the redhorse, although relatively common in the lake in 1950, had apparently been unable to maintain their populations and had gradually disappeared. It is possible that the changes observed in the fish populations resulted from factors of the environment other than from radiation damage.

A very marked accumulation of radioactivity by filamentous algae and plankton growing in seepage areas of waste disposal pits and in the settling basin for wastes of the Oak Ridge National Laboratory was reported by Lackey (24). No analyses of the nature of the contained radionuclides are given, but they were of relatively long half-life since no significant loss from decay was found over a period of 14 days. In some instances, such as seepage areas, many generations must have lived under exposure to moderate doses of radiation. No organisms with any indication that they might have been modified as a result of genetic changes were observed. Toxic concentrations of salts in such seepage areas without reference to radioactivity may have limited the number of species found.

Some studies are being made of the biological accumulation of radioactive materials in connection with disposal of laboratory liquid wastes from the Knolls Atomic Power Laboratory. Routine radiological examinations are made of the effluents, river water, bottom mud, aquatic vegetation, plankton, and various species of fish.

The waste effluents contain uranium and plutonium and various fission product elements. The greater part of the radioactivity is caused by rare earth nuclides, but significant amounts are derived from radiostrontium isotopes and radioruthenium.

Reports of observations made in 1956 (Knolls Atomic Power Laboratory, 1956) show concentrations of radioactivity in the river water well below the maximum permissible concentration in water for continuous exposure, but there has been an accumulation of radioactivity in river mud at stations below the plant. Although radioactive materials are present in very low concentrations, the plankton and fish have accumulated radioactivity. The reports do not indicate a trend toward continued increases in the species analyzed. Most of the fish examined were fry and young fish. The largest percentage of fish identified were shiners, *Notropis cornutus frontalis*. One-third were shad, *Alosa sapidissima*,

while most of the remainder were bullheads, *Ameiurus melas,* goldfish, *Carassius auratus,* and orange spotted sunfish, *Lepomis humilis.*

The highest monthly average of beta-gamma radioactivity for the total adult fish was reported to be 31×10^{-6} μc/g (live weight). The edible portion averaged about 8×10^{-6} μc/g. Bone contained about 10 times the amount found in the muscle.

Most of the accumulated radioactivity was usually in bone. Gill tissue, skin, and gut were also relatively high, while scales and muscle tissue were low. Muscles contained the lowest radioactivity of the tissues examined. No report was made of the isotopic distribution in the tissue, but uranium, plutonium, the radiostrontium isotopes, and radiocerium are known to accumulate in bone. It is probable that the radioactivity of soft tissues was caused chiefly by isotopes of the rare earth elements and cesium.

There are few laboratory investigations of the accumulation of fission products and other radionuclides by fresh-water fish. For the most part, these contribute but little to an understanding of the extent of biological accumulation of radioactivity from stream pollution.

Prosser *et al.* (25), using goldfish in aquaria, observed the uptake and accumulation of radioactivity from mixed fission products and a few other radionuclides. The greatest accumulation of radioactivity from mixed fission products, other than in the feces, was in the intestines. The gills had 1/12 as much as the intestines and the skin and scales and skeleton were still lower in radioactivity. Muscle had the least radioactivity of the tissues. The accumulation in the fish as a whole over a period up to 24 days was usually between 10 and 100 times levels in the water for small fish, and much less for large fish. Radiostrontium was accumulated in the skeleton, gills, and scales, while Zr^{95}, Nb^{95}, and the cerium radioisotopes were concentrated by soft tissues. When Sr^{89} was added to the water, there was a great accumulation in the calcified skeletal structures, but muscle tissue accumulated very little. The concentration of Sr^{89} in the fish as a whole was 10 to 150 times the concentration in the water over a 4- to 15-day interval. About 13 per cent of the total Sr^{89} of the fish was in the viscera and muscles.

Other investigators have used goldfish (26) to measure the accumulation of Sr^{89}, but their tests were of short duration. After 69 hr of exposure the ratio of radioactivity in the ashed internal organs to the concentration in the water was 53.3. The remainder of the tissue, excluding the gills, had a ratio of 35.2.

Of particular interest is a pond experiment in which 500 mc of Sr^{90} were added to a disused filter bed containing 1.25 mil gal of fresh water (27) which had a calcium content of 75 mg/l. Biological samples, including 2- to 3-year-old rudd, *Scardinius erythrophthalmus,* were taken after 42, 133, and 272 days. High concentrations of Sr^{90} were found in filamentous algae, plankton debris, fine particles in the water, bottom sediment, and the gills, scales, and bone of the fish. Low concentrations were found in the fish flesh. Bone was found to have only 27.3 times the amount of the flesh whereas other investigations find almost 10 times this ratio. There appear to be differences in the ability of fish of different species to concentrate radioactivity in various tissues. The concentration of Sr^{90} in the bone, flesh, and scales of the rudd was 71.0, 2.6, and 208.6 times, respectively, that found in the water. Spectrographic analysis of the fish tissue showed that the ratio of strontium in bone and flesh to the concentration in water was 750 and 7.5, respectively.

Radiation effects on aquatic life can best be evaluated from the review of the work in this field by Donaldson

and Foster (28), who gained much of the information from short exposures to x-rays. In general, organisms of the lower and more primitive phyla are more resistant to ionizing radiations than are the higher vertebrates. Algae and protozoa are most resistant. Mollusks and crustaceans, and probably also aquatic insects, are less resistant. Fish are the most sensitive, and are comparable to other cold-blooded vertebrates. The range of dosages (28) required to cause mortality in the different forms is shown in Table IV.

There are variations in the resistance to irradiation of different species and of individuals of a species. In general, radiosensitivity is related to metabolic rate and cell division. The embryonic period is the most sensitive with sensitivity decreasing as age advances.

Although there is investigational work underway, very little is yet known about the effects on aquatic organisms, particularly during their early life stages, of long-continued irradiation from contained radionuclides. Available data on fish and aquatic invertebrates indicate that levels of radionuclides in the organisms which would be within tolerable limits for their use for human food would not likely release sufficient ionizing radiations to damage the organisms themselves. However, further knowledge on the levels of radioactivity accumulation that are damaging to the organisms of aquatic environments is desirable.

Dangerously high values of radioactivity in whitefish caught by anglers in the Columbia River was mentioned above. A large part of this radioactivity was from the accumulation of P^{32}. If other radionuclides were accumulated in like manner from a different type of pollution, a greater hazard might result.

The radionuclides that may be present in atomic wastes, and may be hazardous to man, are Sr^{90}, Cs^{137}, Ru^{106}, Ce^{144}, Co^{60}, Zn^{65}, Cs^{134}, I^{129}, Cl^{36}, Ba^{135}, and Fe^{55}. Judged on the basis of common use and quantity available in streams, I^{131}, P^{32}, Co^{60}, Sr^{90}, C^{14}, S^{35}, Ca^{45}, Au^{198}, Ra^{226}, Pu^{239}, and uranium present the major problems of irradiation inside the body. Because they have a long half-life and are relatively abundant in fission-product mixtures, Sr^{90} and Cs^{137} are the isotopes most likely to be important in the pollution of streams with mixed fission products. Radioisotopes with short or intermediate half-lives may be critical in specific cases of pollution if they are present in heavy concentrations and if they are accumulated in the edible portions of fish. Radionuclides of certain metals present in reactor coolants as corrosion products are now recognized as being of considerable importance.

TABLE IV.—Susceptibility of Different Groups of Organisms to Irradiation*

Organism	Dose Causing 50% Mortality (r)	Dose Causing 100% Mortality (r)
Algae	8,000–100,000	25,000– 600,000
Protozoa	10,000–300,000	18,000–1,250,000
Mollusks	5,000– 20,000	10,000– 50,000
Crustaceans	500– 90,000	5,000– 80,000
Fish	600– 3,000	370– 20,000

* From Ref. 28.

Permissible Levels of Radioactivity

Some concept of the maximum permissible levels for different radioisotopes in natural waters that would allow safe human use of fish from those waters can be obtained from consideration of accumulation of radionuclides in the muscle of fish, the amount of fish eaten, and the safe levels of intake of radionuclides for the consumer. One may assume that an individual might eat a pound of fish per week and have an intake of approximately 15 liters of water per week. On this basis, the fish muscle could have a level of radioactivity from a particular isotope 33 times greater per gram than that considered as safe in an equal weight of water and still not be hazardous food. Actually, of course, consideration

would have to be given to radiation exposure of the individual from several sources received simultaneously.

Although marine fish have a concentration factor for Sr^{90} in their muscles of only about 1, fresh-water fish, and particularly those living in water of low calcium content, have concentration factors somewhat higher, possibly from 5 to 10. Fish accumulate Cs^{137} to relatively high levels in their muscles when mixed fission products are present in the water. This accumulation may be as great as 20 to 50 times the radioactivity level of the water. However, Cs^{137} together with Ba^{137}, its radioactive daughter, is not considered extremely hazardous to man and a concentration of 1.5×10^{-3} μc/ml is given as the MPC for Cs^{137}–Ba^{137} in water. Sr^{90}–Y^{90} is considered to be very hazardous and the MPC for water is 8×10^{-7} μc/ml. In instances of stream pollution with fission products containing significant amounts of Sr^{90}, limitations which permit safe use as drinking water will automatically provide for safe utilization of the fish as food. If Cs^{137}–Ba^{137} were present in amounts approaching the MPC for drinking water, some hazard from the eating of fish might be possible. In the case of other radionuclides which may be accumulated to a high level in the muscles of fish, concentrations in the water well below levels considered safe for drinking could definitely produce hazardous situations from the use of the fish as food. More precise knowledge of the accumulation of particular radionuclides in tissues and organs of our fresh-water fishes is needed.

Detergents as a Factor in Stream Pollution

Household detergents are becoming a problem in many areas where domestic wastes are discharged into streams. In the past few years their use has increased many times and it is probable that there will be a further increase in the future. They have been found in sewage at concentrations as high as 40 mg/l. In water treatment plants it has been found that 3.0 to 5.0 mg/l in the raw water may interfere with flocculation and coagulation. It has also been noted that chlorination may produce unpleasant odors in the presence of detergents, and that in odor-free water, 5.0 mg/l of detergent may produce an unpleasant odor. It is reported that they are not toxic to aerobic or anaerobic processes but that they may produce nuisance algal blooms by increasing the phosphorus content of the water.

Commercial household detergents are mostly anionic in nature and all are subject to biological breakdown except the alkyl benzene sulfonates. It is the latter material, however, which is the surfactant most commonly used in household detergents. The surfactants compose about 18 to 30 per cent of the detergents while the remainder is made up of a builder which is usually sodium tripolyphosphate. Another commonly used surfactant is dodecyl benzene sulfonate which is derived from petroleum.

The toxic component of household detergents is the surfactant. The alkyl benzene sulfonates are very slightly more toxic in hard water than they are in soft water. The average TL_m values for these materials range from 3.5 to 6 mg/l. The values for sodium dodecyl benzene sulfonate in laboratory tests were as follows: 24-hour $TL_m = 4.0$ mg/l; 48-hour $TL_m = 3.5$ mg/l; and 96-hour $TL_m = 3.5$ mg/l. With the household detergents as such, the range in toxicity of those tested was 15 to 85 mg/l. Soaps and commercial detergents are of comparable toxicity in soft waters but in hard waters soaps are only about 2 per cent as toxic.

Amounts of the surfactants which are safe for aquatic life under conditions of continuous exposure are not known. Sufficient data are not yet available and further, various investi-

gators do not agree in their findings. It has been reported that they are not a toxicity problem while concentrations as low as 0.2 mg/l have been reported to be lethal under conditions of continuous exposure.

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MEETINGS OF INTEREST

Jan. 18–22 **Rocky Mountain Water and Sewage Plant Operators School,** University of Colorado, Boulder, Colo. Professor Walter A. Weers, School of Civil Engineering, University of Colorado, Boulder, Colo.

Jan. 25–27 **6th Radiological Health Seminar,** School of Public Health, University of North Carolina, Chapel Hill. Professor Emil T. Chanlett, Dept. of Sanitary Engineering, University of North Carolina, Chapel Hill, N. C.

Jan. 27–28 **Second Sanitary Engineering Conference,** University of Illinois, Urbana, Ill. William J. Downer, Asst. Chief Sanitary Engineer, Dept. of Public Health, Springfield, Ill.

Jan. 31–Feb. 5 **American Institute of Consulting Engineers,** Statler Hilton Hotel, New York. American Institute of Consulting Engineers, 33 West 39th Street, New York 18, N. Y.

Feb. 21–24 **American Institute of Chemical Engineers,** Biltmore Hotel, Atlanta, Ga. F. J. Antwerpen, Executive Secretary, 25 West 45th Street, New York 36, N. Y.

Mar. 1 **Fourth Great Plains Sewage Design Conference,** Castle Hotel, Omaha, Nebr. W. F. Rapp, Jr., Division of Sanitation, State of Nebraska, Lincoln, Nebr.

Mar. 7–11 **American Society of Civil Engineers,** Jung Hotel, New Orleans, La. W. H. Wisely, Executive Secretary, 33 West 39th Street, New York 18, N. Y.

Mar. 16–18 **Twenty-Third Annual Short Course for Superintendents and Operators of Water and Sewerage Systems,** Louisiana State University, Baton Rouge. Dean Fred H. Fenn, College of Engineering, Louisiana State University, Baton Rouge, La.

Mar. 29–30 **Second Joint Conference on Gaseous and Liquid Waste Problems,** Hotel Traymore, Atlantic City, N. J. Mid-Atlantic States Section of the Air Pollution Control Assn., and the New Jersey Sewage and Industrial Wastes Assn.

Apr. 3–8 **6th Nuclear Engineering and Science Conference, 8th Atomic Energy in Industry Conference, 6th International Atomic Exposition,** New York Coliseum, New York. D. P. Reynolds, c/o Engineers Joint Council, 29 West 39th Street, New York 18, N. Y.

Apr. 4–8 **Course on River Pollution, Sewage Disposal, and Trade Waste Treatment,** University of Birmingham, Edgbaston, Birmingham, England. R. F. Wills, Civil Engineering Dept., The University.

METHODS FOR THE DETERMINATION OF SLIMES IN RIVERS

By J. N. Wilson, R. A. Wagner, G. L. Toombs, and A. E. Becher, Jr.

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In recent years there has been increasing interest in the practical aspects and control of attached growths in the sea and in lakes and streams. The terms "sedentary organisms" and "fouling organisms" have been used for those macroorganisms which foul ship bottoms, piers, and other structures in contact with sea water. The German term Aufwuchs has been widely accepted among fresh-water biologists principally as being useful and descriptive for attached growths in general. Ruttner (1) divided the benthos (bottom dwelling organisms) into two associations, Aufwuchs and Ooze: "Aufwuchs comprises all attached organisms, except the macrophytes, including such forms as *Bryazoa* and sponges, which are usually considered as benthos by American authors; also included are the various forms living free within the mat of sessile forms. This is a broader term than periphyton, including both aerial and aquatic forms."

Sanitary microbiologists and engineers have often encountered a specialized kind of Aufwuchs in water supply systems. Troublesome growths of various kinds and origins are termed "biological slimes" or "nuisance organisms" and may include one or more of a number of aquatic organisms from iron bacteria to fresh-water sponges. Yet, in the biological processes of sewage and waste treatment, especially adapted biological slimes are vitally important in the secondary stages of treatment.

Recently, research on slimes has been stepped up. Reference is made to the work of Butcher (2)(3) and his associates in England, and more recently to Heukelekian and Crosby in New Jersey (4). Heukelekian discussed methods for the study of slime growths in channels carrying wastewaters. In the majority of instances, the devices for collecting these growths have been glass microscope slides in a variety of holders. The slides are suspended for varying lengths of time in the water to be tested. Recognizing certain shortcomings of glass as a surface for attachment, Heukelekian (4) experimented with several other materials. He reported that the nature and degree of roughness of a surface does not affect the ultimate quantity of slime produced, but that during the initial stage of growth on a clean surface, glass and glazed tile gave somewhat less slime accumulation than did concrete or asbestos-cement.

For a thorough discussion of the literature on the subject of slime production and attached microorganisms in general, reference is made to the extensive literature review on the subject by Cooke (5).

A recent investigation of pollution in the lower Columbia River from Bonneville Dam to Cathlamet, Washington, and the lower 26 miles of the Willamette River, a major tributary of the Columbia, was conducted to determine, among other things, the extent and effect of bacterial and fungal slimes upon commercial and sports

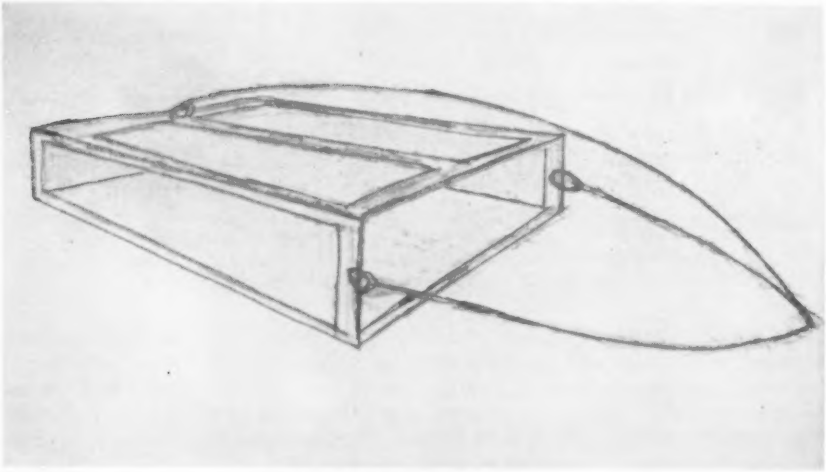

FIGURE 1.—Bottom trawl.

fishing operations and other water uses (6) (7). The principal contributors to the slime problem were sugars and other nutrients from pulp and paper mills in Washington and Oregon and food processing plants in Washington.

At the outset it was clear that existing field methodology commonly used in stream pollution investigations was inappropriate for detection and measurement of slimes in large rivers such as the Columbia. The use of such well-known limnological equipment as the Petersen dredge and Wisconsin plankton tow net indicated the distinct limitations of such devices in the light of the following general objectives prescribed by the cooperating agencies:

1. To locate the areas of active *Sphaerotilus* * growth;
2. To develop methods to correlate the areas of growth with various concentrations of nutrients and certain physical factors; and
3. To determine the amount, condition, and distribution of detached suspended slimes with especial reference to adverse effects downstream from growing areas.

To help accomplish these objectives, three pieces of field equipment were developed or adapted from existing models: (a) The bottom trawl to locate the areas of active *Sphaerotilus* growth; (b) the tile-box sampler to correlate areas of growth and growth characteristics with various concentrations of nutrients and certain physical factors; and (c) the Reighard tow net to determine quality, quantity, and distribution of detached and suspended slimes. In actual practice, the methods and their corresponding objectives were not so sharply defined as the foregoing appears to indicate. Rather, each device had something to offer in the attainment of all three objectives.

Bottom Trawl

Although *Sphaerotilus* may live for a time in suspension, detached from its point of origin, there is a tendency for it to become weighted down with silt, waterlogged sawdust, wood fibers, and other material to such a degree that it will readily sink to the bottom. Thus, extensive sludge deposits are formed. To determine the distribution

* In the report (7), the term *Sphaerotilus* is used synonymously with "slimes" because the sewage bacterium *Sphaerotilus natans* was usually predominant.

and characteristics of these deposits, a bottom trawl has been used to good advantage (Figure 1).

This trawl was developed by the Oregon State Fish Commission to determine the distribution of smelt eggs in the gravel bottoms of deep rivers. The device is 12 in. wide, 5 in. high, and 20 in. long and has sharp edges around the forward, open end. When the trawl is lying on the bottom in position to be dragged, it has metal panels on its top and bottom, and 20-mesh bronze screen on its sides and after end. Because of its light weight (20 lb or about one-half that of the Petersen dredge), ease of handling in the field, and greater certainty of obtaining positive catches (in comparison with the dredge), the bottom trawl has been extensively used as a qualitative, reconnaissance tool.

The procedure used with the trawl is to throw the device as far as possible from the boat and play the rope out to allow quick descent to the bottom, whereupon, with boat in motion, trawling over an estimated 3 to 6 ft of bottom is accomplished before retrieving. By this means a minimum of sand is caught, but slimes settled on or growing from bottom surfaces are dislodged and brought up in the trawl. After visual observation and cleansing by holding the safety rope attached to the posterior end of the trawl, the sampler is ready for the next try.

Tile-Box Sampler

Although *Sphaerotilus* will grow attached to small particles of suspended matter, prolific streaming growths usually are attached to fixed substrates, such as floating logs, piling, rock and gravel, submerged brush, boat hulls, and the like. Therefore, in order to eliminate the factor of availability of suitable attachment surface, and at the same time provide a means for quantitative determination of rate and volume of growth, an artificial surface was devised. The apparatus for ex-

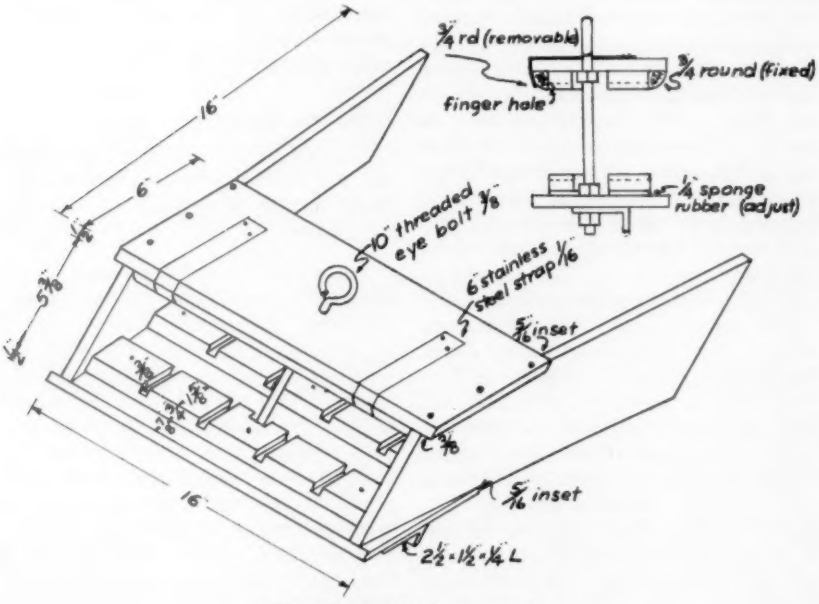

FIGURE 2.—Tile-box sampler.

posure of unglazed ceramic tiles in flowing waters is called a "tile-box sampler" (Figure 2).

The development of the tile-box sampler was completed early in the course of the cooperative investigation of *Sphaerotilus* in the Columbia River (7); however, it was agreed that publication of the laboratory and field methods would await completion of the over-all report (Oct. 1958). In order to test the efficacy of these methods, industrial research groups such as the National Council for Stream Improvement, certain colleges and universities such as Oregon State College and the University of Utah, private consultants, and others tested the devices under variable conditions.

Two sizes were used; the larger, accommodating six 6-in. square tiles; the smaller, four 4¼-in. tiles. Except for some minor details, features of the two boxes are the same. Figure 2 is a drawing of the smaller box.

The box material is marine plywood with side members extended backward at a slight angle to serve as fins. Thus, the device is oriented in the current so that the water passes freely through the open box past the tiles which are held in a vertical position edgewise to the flow. The center eye-bolt is threaded throughout its length to allow use of nuts under the upper panel, and above and below the lower panel. This important provision assures rigidity and ease of insertion and removal of the tiles.

Provision may also be made for holders to suspend 1- by 3-in. microscope slides to facilitate direct fixing, staining, and examination of growth *in situ*.

Additional ballast is required besides the angle iron which is normally mounted beneath the lower panel. Weights should be mounted in such a way that the sampler will be "fin-heavy" rather than balanced at the eye-bolt. The sampler should be suspended in as nearly level position as possible.

In a swift stream such as the Columbia River, the samplers should be tied to fixed structures such as floats at boat moorages, dolphins, and the like. Where representative sampling requires location in or near the main channel where fixed structures may not be available, buoys and anchors must be used. A chain of 1,200-lb test has been found necessary along with a 10-gal buoy and at least a 100-lb anchor. Experience has shown that in waters where the velocity approaches 3 fps, anchors of 100 lb each used in tandem are superior to a single anchor of the same combined weight.

A modification of the original design of the tile-box sampler is described by Gellman (8) of the National Council for Stream Improvement. This device is called the tile and net-grid slime sampler. Instead of relying entirely on accumulation of growth on the tile surfaces, the tiles on one side of the sampler are replaced by a steel-net grid of 1-in. mesh. One grid is held broadside and the other edgewise to the axis of flow. Thus, a qualitative determination may be made of detached slimes which are drifting past the sampling point.

Sampling Procedure

The procedure for sampling growth on the tiles and processing the material in the laboratory is described as follows:

After the box has been held in the stream for the desired period—usually one week in summer and two weeks in winter—it is lifted slowly to the surface, two of the tiles are carefully removed, and the growth is thoroughly scraped from their smooth surfaces (one side of tile is usually ribbed, the other smooth) into a wide-mouth bottle of about one-half pint capacity. A medium-sized steel spatula is satisfactory as a scraper. To rinse the tile, a 3-per cent solution of formalin in distilled water is applied with a plastic

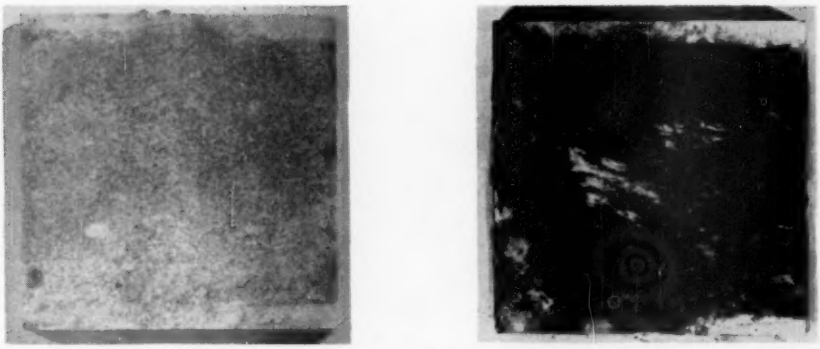

FIGURE 3.—Photographic record of growth on tiles after two weeks at a water temperature of about 16°C. Tile at left was upstream from a major source of pollution; tile at right was downstream from major waste source containing high concentrations of carbohydrates.

squeeze bottle. Growth caught on the leading edge of the tile is not included in the sample. A small amount of slime from the ribbed side of a tile is placed in a separate bottle for microscopic examination and qualitative determination of the living material.

After removal of the sample, the tiles are thoroughly cleaned with scrub brush and cleansing powder, rinsed, and immersed for one minute or more in a strong chlorine solution for disinfection. They then may be reinserted in the tile box.

An alternate or supplemental method which has proved satisfactory is to transport the tile with growth attached to a suitable location where a close-up picture can be taken for the record (Figure 3).

Quantitative Determination of Growth

The following procedure is suggested as a quantitative method for determination of growth from the tiles:

1. Shake sample jar to loosen settled solids.
2. Divide the sample into two calibrated 50-ml centrifuge tubes.
3. Spin solids down in centrifuge for 5 min at 1,800 rpm. Pour off ⅔ of the supernatant, stir both tubes, and combine the heretofore divided sample into one 50-ml calibrated centrifuge tube.
4. Spin combined sample in centrifuge for 10 min at 2,300 rpm.
5. Record total ml of centrifuged solids and the ml of light and dark strata.
6. Pour off ¾ of the supernatant from the centrifuged sample. Mix the contents thoroughly and add the total to a 35-ml tared evaporating dish.
7. Evaporate to dryness (1 hr) and place in 103°C oven for 1 hr. Place sample in desiccator and cool, weigh, and record weight. This gives the weight of total solids.
8. Place the evaporating dish in the muffle furnace at 600°C for 1½ hr. Place in desiccator to cool. Reweigh dish and record results. This is the weight of the fixed solids. The volatile solids is the difference between total and fixed solids.

In a field study where evaluations of physical and chemical factors are made for the purpose of correlation with rate of accumulation of growth on the tiles, each sampler location may serve as a testing station for a variety of determinations, such as water temperature or velocity of river flow. In addition, grab samples or, better yet, a series of samples over a period of

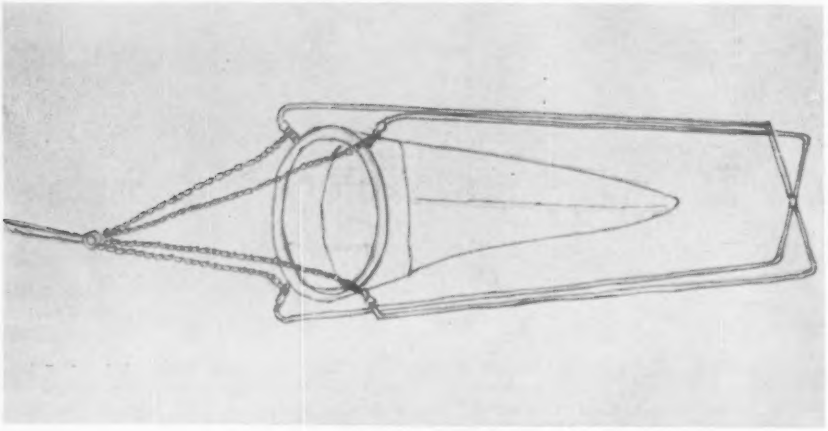

FIGURE 4.—Modified Reighard tow net.

several hours may be collected at the tile-sampler location.

The Reighard Tow Net

The achievement of the third objective, the determination of quantity, quality, and distribution of detached *Sphaerotilus* and its adverse effect on areas downstream from areas of heavy growth is essential to the full and satisfactory interpretation of results from the use of the tile box and bottom trawl.

This gap in existing knowledge became strikingly evident on several occasions when commercial fishermen who had been fishing consistently in an area of active growth with only moderate detrimental effect on their nets and fishing success, suddenly, and usually without warning, encountered extremely heavy suspended masses of *Sphaerotilus*. These moving "slugs" of detached growth followed or moved with a stream freshet. In several instances such a "slug" has been traced downstream by violent complaints from fishermen on successive drifts all the way to the mouth of the Columbia, a distance of 120 miles from the uppermost area of heavy growth. The rate of downstream progression of complaints usually corresponded closely with the estimated time-of-flow of the river at that time.

Because of the growing awareness of the importance of these moving "slugs" of detached growth in the over-all problem on the Columbia River, a means for rapid determination of the location, distribution, and relative abundance of suspended *Sphaerotilus* was sought.

After several months of experimentation using test gill nets (¼-in. hardware cloth mounted in wooden frames held broadside to the current) and conventional plankton tow nets, a modified Reighard tow net was constructed similar to the one described by Welch (9). This device was essentially similar to a conical macroplankton tow net but with the added feature of a framework of four steel rods bent in such a way as to protect the bag and to act as runners to allow the net to be used on the bottom drag if desired (Figure 4).

The area of the net opening is 1 sq ft and the silk bolting cloth is 16 mesh. Mesh size is an important consideration because a cloth of too fine a mesh in a swift stream tends to clog with heavy particles of silt and debris, but too coarse a mesh allows much of the finely divided slimes to escape.

The Reighard tow net is used most effectively by allowing it to trail downstream from an anchored boat. Weights and floats are attached where necessary to regulate the depth of the net. The duration of sampling is timed and the stream velocity past the boat is determined simultaneously by means of a current meter, pitot tube, or similar device. The usual time for collection of a sample is 5 min, after which the catch is washed from the net into a container and preserved in three-per cent formalin. From the knowledge of the stream velocity, duration of net submersion, and area of net opening, estimates are made of the total volume of water sampled.

In the laboratory, the total quantity of slime and debris is determined by one hour's sedimentation in an Imhoff cone. Microscopic examination and per cent differentiation by volume of *Sphaerotilus* versus other organisms and debris may be estimated just as with the samples from tile boxes.

Summary

To achieve the objectives established by the cooperating agencies in the recent investigations of *Sphaerotilus* growths in the lower Columbia River it was necessary to devote considerable time to development and revision of field methodology and laboratory techniques. As a result, the foregoing discussion of the bottom trawl, the tile-box sampler, and the modified Reighard tow net represents the contribution by the investigators to improved methods for determination of slimes in rivers.

Acknowledgments

The writers wish to acknowledge the valuable assistance and suggestions of: Donald L. Benson, Oregon State Sanitary Authority, for suggestions on the trawl and tile-box techniques and the drawing of the tile box; and Mel Currey, Robert A. Taft Sanitary Engineering Center, for certain design features and construction of the first tile boxes.

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* These reports are available in limited supply at the Portland office of the Public Health Service, 211 U. S. Court House, Portland 5, Ore.

IF YOUR 1960 DUES ARE UNPAID SEE PAGE 51

THE OPERATOR'S CORNER

SLUDGE DRYING AND INCINERATION *

By Robert D. Nickerson

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The purpose of this paper is to present cost data on sludge disposal in three sewage treatment plants, together with information on air pollution (deodorization and fly ash collection) and sludge utilization.

While there are many ways of disposing of sludge, it has been found that where large quantities are involved and land is valuable, disposal by drying for later use or by burning is widely practiced. The nature of both of these operations is such that the additional functions of deodorization, fly ash collection, and dispersal of the combustion gases must be considered or else proper disposal will not be achieved.

The plants are located at: Waterbury, Conn.; Camden, N. J.; and Schenectady, N. Y. Each dewaters sludge on drum-type vacuum filters and then flash dries and/or burns the solids. The first two handle raw primary sludge while the third handles digested primary.

Flash drying is generally well known, but it might be well to briefly describe the operation so that the cycle used at each city will be understood. Figure 1 shows a basic flash-drying system attached to a refuse incinerator which is similar to the arrangement at Waterbury. The filter-cake feed is discharged to the paddle mixer where it is thoroughly mixed with previously dried sludge. This action reduces the moisture content of the material to about 35 per cent and it becomes light and fluffy with a relatively large surface area. The mix is then discharged to the cage mill where the damp particles of sludge are dried by the hot gases. The drying is accomplished so rapidly that the process is termed "flash drying."

The drying gases carry the sludge particles upward to the cyclone where centrifugal action separates them. The dried sludge is then discharged through an airlock with a portion going back to the mixer for conditioning while the remainder is either burned or used as a fertilizer. In Figure 1 a refuse incinerator supplies the hot gases for drying as well as a means of burning the dried sludge if this is desired. If not burned, the sludge is air cooled by pneumatically conveying it to storage. Since sludge is an organic material it must be cooled prior to bulk storage or bagging.

Figure 2 shows the basic drying cycle plus a furnace equipped to: (a) burn the dried sludge in suspension, (b) dispose of the ash hydraulically, and (c) collect the fly ash. The Camden installation is of this type.

* Presented at the 31st Annual Meeting, New York Sewage and Industrial Wastes Association; New York, N. Y.; Jan. 22–23, 1959.

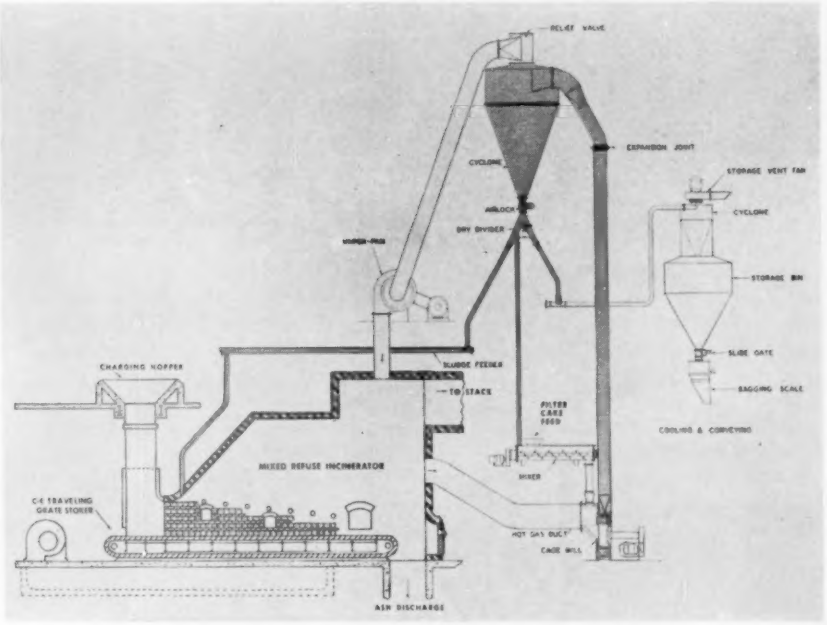

FIGURE 1.—Flash drying system with mixed refuse incinerator.

The Schenectady installation is similar to the Camden type, but has a deodorizing preheater installed in the rear of the furnace. This installation is equipped with a cooling, conveying, storage, and bagging system for dried sludge as shown in Figure 2. Schenectady is equipped to dry or burn at will and to deodorize during either operation. It combines all possible functions in a single system.

Air Pollution

The two principal control measures associated with the heat treatment of sludge are deodorization of effluent gases and fly ash collection.

Deodorization

The use of high temperature to accomplish deodorization is well established in modern practice. The human nose is, in a way, the most sensitive measuring device known and it readily differentiates between foul gases from sludge drying or incineration and the same gases after they have been properly subjected to temperatures on the order of 1,200°F. Even higher temperatures are used in refuse incinerator work since the generally accepted minimum temperature for odor control is 1,400°F or higher.

High stack temperatures are very inefficient thermally. Hence, a heat exchanger is an economic necessity when drying sludge if the gases must be deodorized. The same holds true for incineration unless the heat value of the dry solids is sufficiently high to allow low thermal efficiencies. A tubular-type heat exchanger has been developed for this service which is now in use in many plants.

Sewage sludge is an extremely complex material, and its composition varies from plant to plant and even within the same plant. Thus, heat

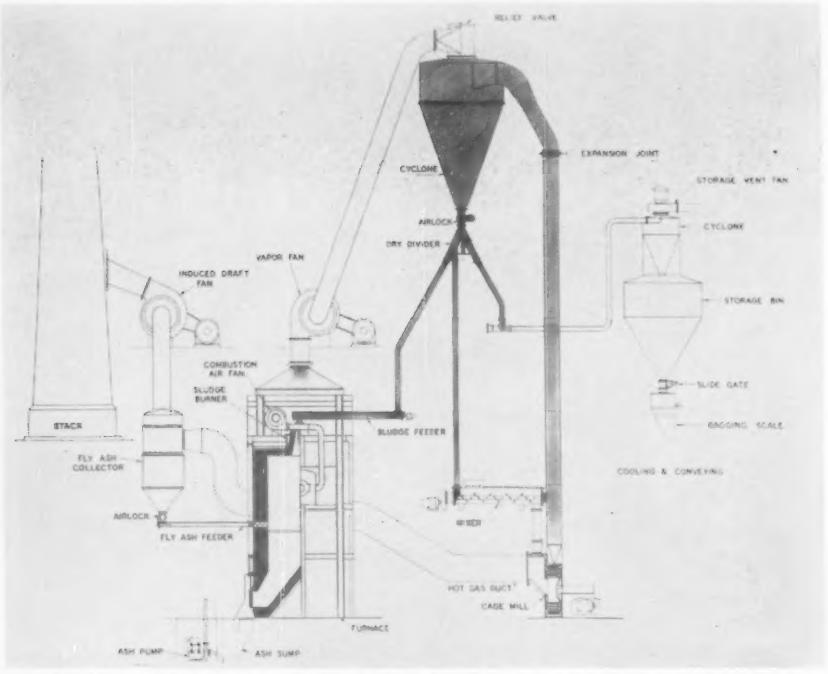

FIGURE 2.—Flash drying system with incinerator, fly ash collector, and hydraulic ash removal.

treatment of the sludge similarly may cause odors of varying composition and intensity. As a result, deodorization may be required. Where it is necessary, the proper application of heat will break down the molecular structure into carbon dioxide, water vapor, and other stable compounds. Since it is impossible to determine accurately all the constituents which sewage sludge may contain, it is necessary to select a temperature which will effectively cause oxidation of the odorous compounds. The temperature which experience indicates will adequately achieve this result is 1,200°F. Partial oxidation, however, which can occur at lower temperatures, may cause an increase in the intensity and type of odor (1). It is highly important, therefore, that odorous compounds be completely stabilized lest the odor actually be increased.

Fly Ash Collection

At present, the most widely used and accepted means of collecting fly ash are high-efficiency centrifugal dust collectors. These units usually consist of a large number of small-diameter cyclones which give high efficiencies even on the finer dusts. The draft loss across such collectors is generally of the order of 2 to 3 in. of water; thus induced draft fans are a necessity.

In general these units will have efficiencies on incinerator dusts of the order of 75 to 80 per cent and even higher. They are suitable for vent gas temperatures up to 650 or 700°F; above these temperatures special heat-resistant construction materials would be required. Such alloy construction, however, is seldom used because at these temperatures the gas viscosities begin to decrease drastically the collection efficiency.

The use of water scrubbers for removing particulate matter from the vent gases of sludge disposal systems is sometimes attractive. Scrubbers, when properly designed and maintained, also have high collection efficiencies, are relatively less sensitive to changes in grain loadings and gas temperatures, and will dispose of the condensable portions of foul gases. However, there are disadvantages such as droplet carry-over (which can cause corrosion), their draft loss is equal to and in certain instances many times that of dry collectors, stack construction must be such that wet gases can be accepted, water must be available and, last but not least, the collected dust in the wastewater must be disposed of.

Dispersion of Combustion Gases

The use of stacks to disperse combustion gases is generally accepted. The height selected should definitely take into account the topography of the site, wind direction, quantity of vent gases, builtup areas, future land use, and even the shape of the sewage treatment plant buildings. A careful analysis of these conditions may lead to the use of short or stub stacks. In general, however, the great majority of installations will require stack heights of 75 ft or more above grade.

Sludge Utilization

Much has been written about the use of sewage sludges as fertilizers and soil conditioners. The activated types are highly regarded and in demand as evidenced by the wide acceptance of the Chicago, Milwaukee, and Houston products. Digested sludges have not enjoyed the same demand, primarily because most soil nutrients are sold on a chemical basis. There is evidence, however, that this condition is changing. There has been a great increase in the non-farm market for organic materials since the Korean War. This market should continue to grow and, as a result, should make the recovery of sludge more attractive as a means of reducing disposal costs.

These sludges are valuable because they improve the soil's structure (2). The moisture-holding capacity is increased, the organic-matter content is increased, total nitrogen rises, and soil aggregation—a most important factor—is greatly improved.

Digested sludges also contain trace elements and are at least the equivalent of manure (3) (4). The proper price for such material could, therefore, be determined by the local cost of manure on a dry solids basis.

It has been estimated that some 250,000 to 300,000 tons of heat-dried sewage sludge is used in this country each year. This does not include the sludge from drying beds or lagoons nor filter cake. In 1958, approximately 22 million tons of fertilizers of all types were used in the United States. There is obviously no basis for concern that increased production of heat-dried sludges will do more than meet about 3 per cent of such a market.

Drying sewage sludge for subsequent sale is a cost-reducing operation, profitable in the sense that the disposal costs are lowered. It offers also one of the only two ways in which a plant can make use of its two by-products—sludge and treated water. Further, the initial equipment cost is often lower, there is no ash disposal charge, and last, but possibly of most importance, there is the public relations factor. For example, Schenectady sells its entire production locally, and enjoys a very high standing among the citizenry.

Cost of Sludge Drying and Incineration

The cost of disposing of a ton of sewage solids varies from plant to plant. When comparisons between plants are attempted, the full effect of the variables is not always apparent

TABLE I.—Sludge Drier Performance at Waterbury, Conn. (1957)*

Item	Design (lb/hr)	Actual (lb/hr)	Ratio of Actual to Design (%)
Filter cake dried	3,900	6,637	170
Moisture evaporated	2,600	3,767	145
Dry solids production	1,170†	1,950‡	166

* Plant design pop., 100,000; design flow, 15 mgd.

† 10% moisture in dry solids not included in this value.

‡ 32% moisture in dry solids not included in this value.

and the validity of conclusions may be doubtful. However, such data should be useful as a guide, and can be valuable in the search for a better way. Some of the variables encountered are: size and type of plant, overhead costs, management competence, city policies, records and cost data, labor productivity, equipment functions, experience, plant design, and site conditions.

In order to make the cost information which follows as useful as possible, the basis of costs in each case is stated.

Waterbury, Conn.

Waterbury's plant produces raw primary sludge which is pumped to holding tanks, then vacuum filtered, dried in a flash drier, and burned in refuse incinerators. All heat for flash drying is drawn from circular-type refuse incinerators. The arrangement of the flash-drying system is similar to that shown in Figure 1.

The sludge is very fibrous. The average grease content on a dry solids basis has ranged from 23.0 per cent in 1956 to 26.3 per cent in 1953. It was 23.5 per cent in 1957.

The grease and fiber make the material unfit for soil conditioning generally. A small amount has been used on the plant grounds with uncertain results.

Tables I and II show performance and cost data for the period 1956–57 for the entire sludge disposal process from the raw sludge pump discharge through the holding tanks, vacuum filters, and flash drier.

The fine performance of the flash drier as shown in Table I is especially noteworthy. These results are similar to those obtained at the Tenafly, N. J., sewage treatment plant before its flow was consolidated into a large plant at Little Ferry.

While cost figures for 1958 are not available at this time, the indications are that they would be about the same as for 1957 on a unit cost basis. All of the sludge in each year was filtered and 81.5 per cent was flash dried and burned in 1957 and 91 per cent in 1958. The remainder was hauled to the refuse dump.

No attempt was made to determine any charges or credits in regard to the use of the refuse incinerators. The heat value of the sludge has not been determined so the net heat dissipation

TABLE II.—Estimated Annual Costs for Sludge Disposal at Waterbury, Conn.*

Item	1956 Costs ($)	1957 Costs ($)
Wages	15,380.00	15,800.00
Chemicals for filtering	0.00	0.00
Filter cloths	110.00	60.00
Fuel oil	0.00	0.00
Power	3,570.00	3,700.00
Supplies and service	3,960.00	4,170.00
Total operating cost	23,020.00	23,730.00
Debt service (20 yr)	19,500.00	19,500.00
Gross annual cost	42,520.00	43,230.00
Operating cost per ton of dry solids	15.32	14.34
Debt service per ton of dry solids	13.00	11.80
Total cost per ton of dry solids	28.32†	26.14‡

* From raw sludge pump discharge to completion of process.

† 1,598 tons of dry solids processed.

‡ 1,654 tons of dry solids processed.

in the incinerators, if any, has not been estimated. The use of hot gases for drying and the return of cool gases for deodorization appear to have a beneficial effect in stabilizing combustion chamber temperatures. Also, as the sludge is burned continuously in suspension, it helps to rapidly re-establish ignition of freshly charged refuse. The reduction in refuse-incinerating capacity appears not to be significant in that little difference is noted in the number of charges taken whether or not sludge is being burned.

It is worth noting that in a plant of this size with the type of sludge processed and the cycle used, that the total "wages" cost for 1957 was $9.57/ton of dry solids.

The sludge disposal facilities including the buildings, equipment, and all changes and improvements cost $330,000.

The sludge disposal facilities are operated six days a week for about 6.4 hr/day. The plant disposes of about 66 per cent more dry solids each day than it was designed to handle. This has actually resulted in considerable savings to the city by eliminating the need for a second shift.

Camden, N. J.

Camden's main sewage treatment plant produces raw primary sludge which is sent to two unheated, covered holding tanks, then to vacuum filters, and, finally, to two incinerators (Figure 2). The plant began operations in Jan. 1956.

The characteristics of the sludge at Camden have varied widely. This was especially true after the plant first started. In 1958, the variations decreased markedly; previously, for example, the heat value ranged from 8,700 to less than 2,600 Btu/lb of dry solids. It also varied widely in the amount of fiber and asphaltic compounds it contained. As a result, it was obvious the sludge was not suitable for use as a soil conditioner, but some recent evidence indicates that the present sludge is usable. This last development offers a possibility of further reducing the cost of disposal.

TABLE III.—Incinerator Performance at Camden, N. J. (1958)*

Item	Design	Actual	Ratio of Actual to Design (%)
Filter cake burned (lb/hr)	10,000	7,200	72
Filter cake moisture (lb/hr)	70	70.6	—
Moisture evaporated (lb/hr)	7,000	5,075	72
Dry solids load (lb/hr)	3,000	2,125	71
Heat value (Btu/lb of dry solids)	5,200	3,417	66
Heat release (mil Btu/hr)	15.60	13.54	87
Thermal efficiency (%)	48.0	41.8	87

* Contributory pop., 380,000; flow, 17.8 mgd.

The incinerators at Camden flash dry all the filter cake and burn the dried sludge in suspension. Ash is moved hydraulically to a lagoon. The water leaches away rapidly and a person can walk over newly deposited ash 5 min after it is discharged. The ash makes excellent fill, but is of no other use.

Table III shows the performance of the vacuum filters and the incinerators. It should be noted here that the filters and the incinerators must balance each other near one of the incinerator design points if optimum results are to be obtained. The design points are: (a) dry solids processing rate, (b) evaporation rate, and (c) heat release rate.

Table III shows that for 1958 the heat release factor was about 87 per cent of design or 13.54×10^6 Btu/hr. While this is good operation, the data indicate that the way to improvement is to increase the solids loading from the filters while keeping cake moisture to a minimum. This sounds simple, but it has not been an easy matter to condition the variable sludges arriving at this plant. It was particularly difficult during 1956 and part of 1957 when variations were extreme.

The data in Table III are based on

TABLE IV.—Estimated Operating Costs for Sludge Disposal at Camden, N. J. (1958)

Item	Cost
Wages	$18,704.80
Chemicals for filtering	23,958.62
Filter cloths	270.00
Fuel oil	11,366.06
Power	7,316.40
Supplies and service	1,390.50
Total	63,006.38
Total cost per ton of dry solids (record)	21.50*
Total cost per ton of dry solids (adjusted)	17.05†

* Based on 2,930 tons.
† Based on 3,700 tons.

plant records and the sludge quantities have not been adjusted upward even though it is known that the belt scales was reading low. By using other data, it was estimated that the sludge disposed of could have totaled 3,700 tons of dry solids for the year. Where this higher figure is used, it is noted as "adjusted." It is probable that the actual tonnage was somewhere between the two.

Present operation is 5 days a week for 14 hr/day plus startup time. The average warmup time for each startup (including weekends) was less than 30 min. The average fuel consumed per startup was only 39 gal and the furnaces usually were idling for varying periods of time waiting to receive filter cake. All of this reflects good startup practices by the operating personnel.

There has been no refractory maintenance of any significance on the furnace walls or the flat arch. Some work, of course, has been done around the oil burner cones and several tiles have been replaced in the sludge burners.

Maintenance for parts and labor of the incinerators after three years of operation cost 36¢/ton of dry solids; the charge against the vacuum filters was estimated at 11.5 ¢/ton.

Table IV shows the estimated operating costs for 1958 for vacuum filtration and incineration. No costs were included for the sludge holding tanks. The costs are, therefore, on a somewhat different basis than costs for Waterbury.

The "wages" item includes the full salaries for operating crews, but not for maintenance labor. Maintenance labor is included under "supplies and service."

The unadjusted labor cost was $6.40/ton of dry solids. The chemical cost on the same basis was $8.18. The adjusted labor cost was $5.08/ton of dry solids for both vacuum filtration and burning. The adjusted chemical cost for conditioning the sludge was $6.48/ton of dry solids.

The cost of burning only, including such items as labor, all fuel, power, and maintenance was $9.25/ton of dry solids based on 2,930 tons or $7.39/ton based on 3,700 tons. The cost compares favorably with other plants of similar size and indicates a creditable operating procedure. As the flow increases at Camden to an anticipated 30 mgd or more, the labor cost will be about halved by operating both incinerators at the same time with the present crews.

Schenectady, N. Y.

Schenectady's plant disposes of digested primary sludge as a soil conditioner under the trade name Orgro. The process includes vacuum filtration followed by drying with high-temperature deodorization in a combination drier and incinerator. The heat equipment can flash dry or incinerate at will. Deodorization at 1,200°F is obtained by the use of a tubular preheater which results in a stack gas temperature of about 500°F.

The only basic difference between the Camden incinerators (Figure 2) and the Schenectady installation is the inclusion of a deodorizing air preheater in the latter. The preheater is simply added to the rear of the furnace behind a refractory curtain wall and is in place for use whether the sys-

tem is drying or burning. The Schenectady plant consistently deoodorizes at high temperature and has never had an odor complaint.

Table V gives a brief description of the plant as to its size and the sludge disposal process. Performance of the heat equipment is stated for 1958 along with the moisture content and load generated by the filter equipment.

Table VI shows the estimated operating costs for vacuum filtration and heat disposal for 1958 to be $5.04/ton of dry solids. This includes the cost of vacuum filtration using lime and ferric chloride for conditioning, flash drying using oil as a fuel, operating labor, power, maintenance, and supplies. It does not include any charges against sludge disposal for the operation of the digesters or their maintenance. It should be noted that the sludge disposal costs given in Table VI are on a different basis than costs for Waterbury. The revenue obtained from the sale of Orgro results in probably the lowest operating cost of any comparable plant utilizing heat treatment. The Schenectady operation is relatively small, but in spite of this the sale of the sludge as a soil conditioner results in low disposal costs.

It will be noted that the labor cost is about $10/ton of dry solids. This was determined on the basis of the time spent in actual operation of the disposal equipment including servicing. It does not include janitor or cleanup service. The other costs chargeable to the operation such as chemicals, fuel, power, bags, services, and supplies (which includes maintenance parts and labor) were all obtained from readily available and well-kept plant records.

TABLE V.—Sludge Drier Performance at Schenectady, N. Y. (1958)*

Item	Design	Actual	Ratio of Actual to Design (%)
Filter cake dried (lb/hr)	5,000	3,600	72
Filter cake moisture (%)	70.0	68.2	—
Moisture evaporated (lb/hr)	3,500	2,450	70
Dry solids load (lb/hr)	1,500	1,095	73
Moisture in Orgro (%)	10.0	5.2	—

* Contributory pop., 110,000; flow, 10 mgd.

TABLE VI.—Estimated Operating Costs for Sludge Disposal at Schenectady, N. Y. (1958)*

Item	Cost
Wages	$2,910.00
Chemicals	1,941.00
Filter cloths	104.00
Fuel oil	2,380.00
Power	1,030.00
Bags	1,080.00
Supplies and services	298.00
Gross total	9,743.00
Revenue and credit†	8,230.00
Net total operating cost	1,513.00
Total cost per ton of dry solids	5.04

* For vacuum filtration, drying, burning, deodorization, and fly ash collection.

† Revenue of $7,315 plus $915 credit for Orgro to park department.

Revenue from the sale of Orgro amounted to $7,315 in 1958. Since a portion of the available material was used by the city park department, a credit for that amount would bring the total to $8,230.

Over the last five years the Schenectady plant has received a total cash revenue from Orgro amounting to $27,000. In addition, $11,000 worth of Orgro has been used by the City. Thus, a total of about $38,000 worth of soil conditioner has been produced since the modernized plant went into operation.

Orgro is sold strictly as a soil conditioner and in a simple manner; the customer comes to the plant and picks up the bags along with a pamphlet which describes the product. No analysis, either chemical or organic, is printed on the bag. The City assumes no obligations nor does it make any commitments. The State under these circumstances does not require the plant to be licensed.

It should be noted that other advantages accrue where sludge is disposed of in the Schenectady manner.

TABLE VII.—Operating Costs for Typical Day at Schenectady, N. Y. (Feb. 6, 1958)*

Item	Cost
Wages	$ 30.40
Chemicals for filtering	22.35
Filter cloths	1.66
Fuel oil	27.30
Power	12.04
Bags	13.60
Supplies and service	3.10
Total	110.45
Revenue	113.00
Operating profit	2.55

* For vacuum filtration, drying, and high-temperature deodorization.

First, there is a public relations value and, second, there is no ash-disposal cost. Of the advantages, that of public relations is believed to be the most important because as a result the people get to know the plant and can more fully appreciate its function.

The Schenectady price for a 65-lb bag of Orgro is $1. This is a sale price of about 1.5¢/lb and it is considered a bargain when compared with other materials quite similar to it. It is also a bargain where activated sludge is concerned because its retail price is about one-third that of dried, activated sludge yet it will supply about the same quantity of nitrogen when two pounds of Orgro are used for one pound of activated sludge.

Table VII gives estimated operating costs for a typical day, Feb. 6, 1958, for the entire process including vacuum filtration, flash drying and high-temperature deodorization, cooling, conveying, and bagging. The income which remained after deduction of the day's operating costs indicates that on some days at Schenectady the sludge-disposal portion of the plant is self-supporting from an operating-cost standpoint.

The difference between the net operating cost of about $5.00/ton of dry solids in Table VI and the small operating profit shown in Table VII, is accounted for by the fact that some sludge was incinerated in late winter. This was necessary since it was thought that the digesters were becoming overloaded. Incineration is an expensive operation for Schenectady because of the excellent salability of Orgro.

The demand for the dried material occurs in the spring, summer, and fall and every effort is made to store the winter load of solids in the digesters in order to meet the spring demand for Orgro.

The daily operating schedule at this plant for 1958 averaged 5.5 hr/day. The average time to start the unit, including the vacuum filters, averaged 0.8 hr. This average time includes quite a few warmups when two or more days elapsed between starts. There were also a number of startups with a one-day interval.

After five years of operation at Schenectady on a non-continuous basis there has been no refractory maintenance of any significance; there has been some work on the oil burner cones. The refractory walls and the flat arch are in excellent condition. The deodorizing preheater and the rest of the drying system are in first-class condition.

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ELECTRICAL MAINTENANCE IN SEWAGE TREATMENT PLANTS*

By William B. Bustard

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Electrical maintenance and safety in any plant depend on three main factors: (a) the design and installation of equipment, (b) the training of operating personnel, and (c) the quality of the maintenance program.

Design

To insure safe operation and minimum maintenance costs, the following design considerations are of prime importance:

1. The choice of the type and voltage of the system must be based on a sound evaluation of initial loads with adequate provision for future expansion;
2. Careful selection of equipment and wiring components;
3. Proper grouping of equipment on feeder circuits and load centers with respect to normal sequence of operation;
4. Adequate grounding of system and equipment;
5. Location and protection of control equipment;
6. Provision for emergency power for preferred circuits; and
7. Suitable alarm and signal circuits.

Distribution System

To select the proper type and voltage for the distribution system, the designer must have complete information as to the total connected loads, maximum horsepower of individual motors, sequence of operation, and the degree of reliability required for the plant. The degree of system-reliability depends directly on the economics of the situation: how much can the client afford to pay for reliability? There are no set rules of thumb to cover this point. Each plant must be considered on its own merits. Neither are there any reliable rules of thumb for estimating in advance the approximate horsepower required for a particular plant. Similar plants will vary immensely in power requirements, depending upon topographic location and the amount of pumping required.

Generally speaking, small and medium-sized plants which are not spread over too wide an area can readily be supplied from a single substation at 440 v. The largest motor which would normally be operated on a 440-v system is 150 hp. Larger plants spread over a wider area and employing larger motors should go to a higher distribution voltage—2,400 or 4,160 v, with motors above 150 hp operating directly on distribution voltage, and smaller motors operating at 440 v through step-down unit substations or power centers.

As to reliability, this brings up the question of whether to use a simple radial distribution system, or a split system with more than one primary feeder and tie circuit breakers. There are several variations which might be used, depending on the degree of system reliability required and the amount of money available.

Equipment Selection

The question of reliability also enters into the selection of equipment:

1. In selecting substation and power-center equipment, the first consideration is the protection to be used.

*Presented at the 31st Annual Conference, California Sewage and Industrial Wastes Assn.; Long Beach, Calif.; Apr. 29–May 2, 1959.

Fuses are simple and offer the lowest cost protection, but they are harder to coordinate and require longer outage periods in case of trouble. Circuit-breaker protection is always preferable if it can be obtained. Coordinated relaying of circuit breakers will result in greater reliability.

2. Consideration must be given to future plant expansion. Thought should be given to the possibility of adding future power centers; adding future feeder circuits from power centers to additional distribution panels; and adding additional branch circuits from distribution panels to individual loads. In other words, the system should be left open for expansion at many points. No single part of the system should be loaded to capacity initially except perhaps branch circuits to individual loads which are fixed. Neglect of this principle at the beginning will lead to overloading of circuits and unsafe operation at later dates.

3. The selection of motors for sewage treatment plants is extremely important. The location and application of each motor should be considered carefully. Explosion-proof motors should be used wherever the possibility of a concentration of explosive vapors might occur.

Totally enclosed motors or drip-proof, splash-proof motors should be used wherever they are to be subjected to the weather or hosing. Open-type motors should be used only in clean, dry locations.

Ball bearings generally have proved to be better for high-speed motors which are not subjected to shock loads; sleeve bearings are suitable for slow-speed motors or high shock loads.

The majority of motors for sewage treatment plant applications will be squirrel-cage induction motors, but synchronous motors can be used to good advantage for power factor correction on compressors, pumps, or similar applications requiring large motors. They must, however, be used only in clean, dry locations.

4. The best motor will not operate properly unless proper control equipment is provided. This equipment must not only provide proper starting and stopping control for the motor, but it must provide adequate overload and under-voltage protection. Economics will dictate the amount of protection which must be provided, depending on the value of the motor and the importance of continuous, trouble-free operation.

Equipment Grouping

Motor branch circuits should be grouped on load centers with respect to normal sequence of operation, thus rendering control and trouble-shooting much simpler.

Grounding

Proper grounding of the system and all operating equipment is one of the most important safety requirements of a plant. This is a relatively inexpensive item if designed initially into the system, but is quite expensive to provide after a system has been installed improperly.

Location and Protection of Equipment

The location and physical protection of control equipment is a vital factor both for safety of personnel and for proper maintenance. As far as possible, control equipment should be located in clean, dry places, protected from explosive gases. It is possible to locate the motor starters in such protected areas, and have only the master push buttons or other master control devices located in less desirable areas. These devices are smaller and easier to protect.

Emergency Power

All equipment which must be kept in continuous operation at all times should be grouped on preferred cir-

cuits with some provision made for an emergency source of power in case of failure of the normal power supply.

Alarm and Signal Circuits

A suitable alarm and signal system should be provided for normal supervision of operation and for quick intelligence in case of trouble. A properly installed alarm system will cut down stoppages and reduce the outage time when trouble does occur.

Installation and Testing

The very best design can be ruined by poor installation. Selection of the proper types of conduit, wire, and wiring devices for each application will save serious maintenance trouble later. Coated conduit for resistance to corrosion is now available at little or no premium. Explosion-proof or vapor-proof wiring devices should be used freely, even where not specifically required by codes. They pay off in lower maintenance costs. Moisture- and heat-resisting insulation should be used throughout, since the wire must last for the life of the plant. The labor element in wiring costs is such that it pays to use the best materials available.

Extreme care in handling equipment, pulling conductors, making splices and joints, and the proper mounting of wiring devices, are all factors which will result in lower maintenance costs. Close supervision and inspection of wiring details is absolutely necessary, since much of this work is not visible after installation. A large contributor to high maintenance costs is careless workmanship, a byproduct of lax inspection.

The final opportunity of the engineer to protect his design is to see that all equipment, wiring, and devices are given a thorough test before being placed in service. He should make checks for circuit continuity, ground tests for all feeders and branch circuits, and resistance tests of all system and equipment grounds. Each individual piece of equipment should be started under careful observation and checked to be sure that the motors are not overloaded.

Maintenance

Education of Operating and Maintenance Personnel

Operating personnel should be thoroughly indoctrinated in the proper procedure for normal starting, stopping, and control sequence of all electrical equipment. They should also be instructed as to methods of cleaning external surfaces of motors and enclosed electrical equipment and surrounding areas. They should be advised as to which motors and enclosed control devices will withstand hosing, and which pieces of equipment should be kept dry. A careful indoctrination of all operating personnel in the rules of electrical safety is also important.

The cooperation of operating personnel in calling the attention of the maintenance personnel to any unusual condition or noise will also result in better maintenance and less loss of equipment.

No mechanical work or remodeling should ever be undertaken without first requesting the electrical maintenance crew to protect the electrical equipment in the area from dirt and accidental contact.

It hardly needs to be mentioned that maintenance personnel should be educated in the proper maintenance procedures for each class of equipment, referring as necessary to the manufacturer's detailed instructions for specific pieces of equipment.

Manufacturer's Data

Each new plant should have a complete file of manufacturer's instruction sheets, operating instructions, and parts catalogs. Maintenance personnel should be thoroughly familiar with this file.

Record Card File

A card file should be set up containing the name-plate data for each piece of electrical equipment, with space on the card for a complete record of all tests, inspections, and repairs. The initial megger readings, taken when the equipment is new and dry, should be recorded for comparison with results from future tests.

Routine Maintenance Schedule

Depending on the severity of service, a regular maintenance schedule should be established as follows:

1. Cleaning. This is one of the most essential items for good maintenance. Cooperation between operating and maintenance personnel in this respect will eliminate a high percentage of maintenance troubles.

2. Inspection. Frequent, routine inspections for cleanliness, unusual noises, abnormal heating, or other indications of trouble should be made of all electrical equipment.

3. Tests. A definite schedule should be set up for a thorough test and routine maintenance of every power and control circuit in the plant. Depending on operating conditions, each circuit should be checked at intervals of not more than six months. Such a check should incorporate the following procedures:

a. Disconnect each branch motor circuit and give the complete circuit a megger test for insulation resistance, including motor windings and all related control circuits. Record all megger readings on the equipment record cards and compare with previous readings.

b. Check each motor, especially induction motors, for: worn bearings, moisture, overloading, single-phase operation, and poor insulation.

Dust and dirt are usually contributing factors to poor performance or complete failure. Some forms of dust are highly conductive and contribute materially to insulation breakdown. The effect of dust on the motor temperature through restriction of ventilation is another reason for keeping the motor clean.

Moisture is one of the most subtle enemies of motor insulation. Around sewage treatment plants and pumping stations, moisture is the prime enemy. Constant vigilance must be maintained toward keeping the insulation dry.

The life of a winding depends on keeping it in its original (or new) condition as long as possible. In a new machine, the winding is snug in the slots and the insulation is fresh and flexible; being newly treated with varnish, it is resistant to the deteriorating effects of moisture and foreign matter. This condition is best maintained by periodic cleaning, followed by varnish and oven treatments.

One condition which frequently hastens winding failure is movement of the coils caused by operating vibrations. After insulation dries out, it loses its flexibility and the mechanical stresses caused by starting, as well as the natural stresses of operation under load, will precipitate short circuits in the coils and possibly failures from coils to ground, this usually at the point where the coil leaves the slot. Periodic varnish and oven treatments properly carried out so as to fill all the air spaces caused by drying and shrinkage of the insulation, thereby maintaining a solid winding, will also provide an effective seal against moisture.

The preceding comments apply to stators and wound rotors. Squirrel-cage rotors are more rugged and in general require less maintenance than wound rotors, but they may give trouble because of open circuits or high-resistance points between the end rings and rotor bars. The symptoms of such conditions are in general the same as with wound-rotor motors—slowing down under load and reduced starting

torque. Such conditions can usually be detected by looking for evidence of heating at the end-ring connections, particularly when the motor is stopped after operating under load.

Any fractures in the rotor bars will usually be found either at the point of connection to the end ring or at the point where the bar leaves laminations. Discolored rotor bars are also evidence of excessive heating. Routine motor checks, therefore, should consist of a careful visual inspection for loose coils, insulation cracks in end connections, dust and dirt in ventilating passages, plus the following tests:

(1) Megger test for insulation resistance (compare with reading of new winding).
(2) Feeler-gauge test of air gap for indication of worn bearings. Four measurements should be taken 90 deg apart and compared with previous readings. If feeler-gauge check indicates a worn bearing, it should be replaced immediately.
(3) Bearings should be disassembled and inspected periodically and lubricated in accordance with manufacturer's instructions. (The manufacturer's instructions—depending upon the type of bearings—will indicate the desired frequency of such periodic checks). On observing any indication of overheating of a motor, the load should be checked immediately.

c. Check all motor starters and other control devices for grounds, insulation resistance, loose or dirty magnetic circuits, burned or dirty contacts, and any other unusual condition. Note that the design of magnetic circuits and contacts varies with different manufacturers, and may require different maintenance procedures. All magnetic contact surfaces must be kept smooth and clean, and shading coils should be checked. Some electrical contacts should be cleaned and dressed, while others should be left alone unless burned down enough to require replacement. Whenever contacts have been burned and require replacement, it is usually best to replace the contact springs too, since the contact heat has probably weakened the springs. Magnetic circuits should be checked for firm, smooth closure. Poor closure of the magnetic circuit will cause magnetic hum and contact chattering, and eventually will cause the operating coil to fail. Check all terminals and connections for tightness, giving special attention to the terminals of the thermal-overload relays. Poor connections on the heater elements will cause excess heat and change the calibration of the relays.

d. Emergency circuits which are connected by automatic transfer switches may operate only at rare intervals. It is important, therefore, to test them at frequent intervals by actually tripping out the normal service to insure that the emergency transfer system actually works. If such a test is not practical, then a simulated test may be worked out to make certain that the system will be operative when an emergency occurs.

e. Since alarm circuits only function when some unusual condition exists, it is important to make frequent tests of these circuits. Such tests can usually be made without interrupting normal operations.

f. Normally it is not possible to take any of the main power equipment out of service for testing. This can usually be done only when arrangements have been made for a major shutdown for other reasons. It is quite important, therefore, to keep this equipment clean, inspect it frequently, and make sure that proper protection is provided against abnormal conditions such as overloads, system faults, and voltage surges. Oil-filled transformers and circuit breakers should be checked by

testing oil samples annually if possible.

Conclusion

Since modern design leans toward more and more use of automatic control systems, a preventive-maintenance schedule must be adopted to ensure trouble-free operation. With a properly designed plant and a thorough maintenance program, there is no excuse for either accidents or burned-out equipment.

PAINTS AND PAINTING *

By Kerwin L. Mick

Chief Engineer and Superintendent, Minneapolis-St. Paul Sanitary District, St. Paul, Minn.

Of the protective coatings available for metal, paints are by far the most universally used because of their relatively low cost, ease of application, and choice of colors.

Prime Coats

The primer for steel work should contain a rust inhibitor and should act as a bond between the metal surface and the succeeding paint coats. Perhaps the most satisfactory general purpose primer for steel work in sewage plants is one containing zinc chromate–iron oxide pigments in a phenolic resin–tung oil varnish vehicle. In many cases red lead is a satisfactory substitute for all or part of the iron oxide content of the pigment. For submerged steel work, bituminous coatings are usually applied, without any separate primer. The phenolics and the vinyls are also suitable for some submerged exposures.

The so-called grease coatings are sometimes used, without a primer, to protect steel surfaces, both submerged and not submerged. These consist of bituminous, waxy compounds containing chemical rust inhibitors. They have the advantage of being quickly and easily applied, particularly in locations where the surface to be protected is difficult to thoroughly clean and dry. They remain rather soft and plastic, however, and cannot be used on surfaces subject to abrasion or rubbing, although damaged areas may be quickly re-coated. At the Minneapolis-Saint Paul Sanitary District they are used to protect the ends of the vacuum-filter drums and on metal work in several small pits or sumps. They are not very resistant to weathering.

Top Coats

Top coats serve to protect the prime coat and as a decorative surface. The type of resin used in the varnish vehicle for the top coat imparts certain characteristics to the finished paint, and together with the drying oil–resin ratio or "length," largely determines its suitability for use under a given exposure. The various types of resins commonly used include the phenolics, the vinyls, the alkyds, the epoxys, and chlorinated rubber. The principal characteristics which they impart to the paint are discussed below.

Characteristics of Paint Resins

Phenolics

Phenolic resins provide excellent resistance to moisture and moderate resistance to mild chemical environments.

* Presented at the 32nd Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Dallas, Tex., Oct. 12–15, 1959.

They are superior to alkyds in this respect, but inferior with respect to outdoor weathering. Short oil-length formulas give maximum moisture and chemical resistance and should be used in interior paints, while exterior paints should be based on a medium or long oil-length varnish. For maximum durability the oil used with the phenolic resin should be largely tung oil. For resistance to chemicals, phenolics are inferior to vinyls or chlorinated rubbers. To reduce their cost, phenolics are often modified with other rosins but this reduces their durability and chemical resistance.

Vinyls

The vinyls have generally good chemical resistance and are also abrasion and weather resistant. They have good resistance to acids, alkalies, oils, and most solvents. They are difficult to apply, however, requiring a thoroughly cleaned surface and several coats in order to build up a satisfactory film. New primers and heavier-bodied vinyls have recently come on the market, however, which are claimed to be less difficult to apply. They dry rapidly and show good adhesion to old paint films of the same type, thereby being more adaptable to a touch-up program of year-by-year maintenance than the phenolic systems.

Alkyds

The alkyd varnishes have excellent weathering characteristics, with excellent gloss and color retention. They do not withstand continuous immersion, however, and are not very resistant to chemicals. They are inferior to phenolics for interior paints in sewage plants, but may be superior for some outdoor applications.

Epoxys

The epoxy resins are relatively new but show considerable promise in respect to improved adhesion and resistance to chemicals. They have a rapid setting time. Their resistance to non-oxidizing acids, caustics, and most solvents is excellent. They have poor resistance to oxidizers, such as chlorine, however, and may not be satisfactory for outdoor weathering exposures or for submerged exposures.

Chlorinated Rubber and Neoprene

Chlorinated-rubber and neoprene resins provide excellent resistance to many acids, alkalies, and mineral oils, but poor resistance to animal and vegetable oils.

Silicones

The silicone resins are among the best heat-resistant paints available for use on breechings, stacks, furnaces, etc. They provide very good service at temperatures up to 600°F and are often satisfactory at temperatures from 750° to 900°F. They are expensive.

Choice of Paints

A brief listing of some of the paints of choice for various conditions of exposure in sewage works may be of interest.

1. *For steel frequently but not continuously wet, exposed to weather, high humidity, and industrial atmospheres.* Iron oxide and/or red lead–zinc chromate–alkyd varnish primer; alkyd top coats. Phenolic may be used instead of alkyd vehicles as second choice.

2. *For steel continuously immersed or wetted or in highly humid air.* Iron oxide and/or red lead–zinc chromate–phenolic primer and phenolic top coats. Vinyl paints, bituminous paints, or chlorinated rubber paints are also suitable. The vinyls require the most complete surface preparation before painting.

3. *For surfaces subject to abrasion.* Neoprene; short-oil alkyd, phenolic,

or vinyl paints; coal tar enamel if not exposed to sunlight. Sand reinforcement of pigments improves the abrasion resistance. The sand is usually tossed or blown onto the paint while the second coat is still wet. After drying, any loose sand is brushed off and the final coats of paint are applied. A sand covering of about 0.1 psf is sufficient. Sand should not be used with vinyls, however, as those coats are too thin and fast drying.

4. *For galvanized iron.* Let the surface weather for six months prior to painting, or pretreat by cleaning with a grease solvent followed by phosphoric acid, or use zinc-dust–zinc oxide primer followed by conventional top coats. Do not use vinegar or dilute hydrochloric acid for pretreatment.

5. *For concrete.* Cement-water paints, resin-emulsion paints, or chlorinated-rubber paints. If new concrete, pretreat with a 3-per cent phosphoric acid–2-per cent zinc chloride solution, allow to dry, and brush off any loose or powdery deposits. The cement-water paints are excellent if good washability is not required. Latex paints are very good for decorative painting of concrete-block walls. For concrete floors the chlorinated-rubber paints are best. Unfortunately floors are very difficult to keep properly painted because a paint film less than 0.1 in. in thickness must withstand all the abrasion of traffic.

Surface Preparation and Paint Application

Surface preparation includes the removal of mill scale, rust, dirt, grease, oil, and damaged paint films. Available methods for accomplishing this include sandblasting, chipping, wire brushing, scraping, sanding, or washing with various solvents or cleaners. Although sandblasting is perhaps the only method of obtaining an absolutely clean surface for painting, it is so expensive and difficult to do that it is seldom employed except in the most critical paint jobs. For maintenance painting in general, surface preparation usually includes as a minimum the use of power wire brushes and power sanders. Excessive power brushing should be avoided as it may result in a smooth burnished surface to which paint will not adhere well.

Paint application by either brush or spray is satisfactory, although there is some evidence to indicate brushing is slightly superior for the prime coat and spraying for top coats. Vinyl paints are best applied by spraying. Roller coating works best on large, smooth areas such as tanks or walls, and it is being used with increasing frequency. Production rates approaching those for spraying are possible. With rollers it is difficult to adequately paint such surfaces as welds, pits, rivet or bolt heads, edges, and corners. A brush should be used to supplement the roller on such areas.

Sources of Information

There are two paint manuals which are at present the most up-to-date, authoritative, and complete sources of information on the proper selection and use of paints (1)(2), and the reader need not be a paint expert to understand them.

The Army Corps of Engineers Paint Manual for New Construction and Maintenance was issued in 1956, and it comprises 147 pages in large, easily read print (1). It is for sale by the Superintendent of Documents, Washington 25, D. C., for 75 cents. A large percentage of its contents may be considered applicable to sewage works painting, although, of course, it was not specifically directed to this field.

The Steel Structures Painting Manual (2) was issued in 1954 and 1955 in two volumes totaling 715 pages and may be purchased (either volume for $6 and both for $10) directly from the Steel Structures Painting Council. This council, sponsored by 19 technical societies and associations, was organized

in 1950 to investigate the confused situation in regard to paints and protective coatings and to issue recommendations. While it is an encyclopedia of information on all phases of the subject, the intent of the manual is to provide a fast and accurate means of selecting and specifying the painting of steel. This is done with the aid of tables and specification numbers. Nine standard paint systems are set up, with specifications for the individual paints, including 12 primers and 13 top coats. The Council intends to continue testing new and improved paint systems.

Sources of several other recent discussions of paints and painting are listed below (3)(4)(5).

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3. Estrada, H. J., "Evaluating Protective Coatings." THIS JOURNAL, **31**, 2, 235 (Feb. 1959).
4. "Sewage Treatment Plant Design." FSIWA Manual of Practice No. 8, p. 356. Federation of Sewage and Industrial Wastes Assns., Washington, D. C. (1959).
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TIPS AND QUIPS

Strubing

Calumet & Hecla, Inc., will start experimental production this fall of light-wall seamless metal tubing that can be shipped in ribbon form and inflated at the point of use (Figures 1 and 2).

The new material—to be known as "Strubing" (strip tubing)—holds promise of major innovations in industries as diverse as construction, electric power distribution, communications, rockets and missiles, farming, packaging, chemical, and general manufacturing.

Strip tubing offers two major advantages: first, point-of-use inflatability makes it possible to ship thin-wall tubing economically since only the tube "walls" are shipped and not the "hole"; second, the process used in making Strubing, technically classified as cold rolling, provides an economical means of producing thin-wall tubing of materials and in thicknesses either unavailable today or available only at a prohibitive cost.

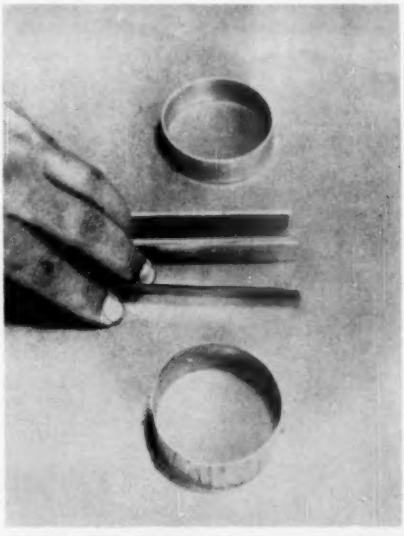

FIGURE 1.—Strip tubing—flat and inflated.

FIGURE 2.—Strip tubing being inflated.

"Lining by inflation" techniques might be used to construct low-cost, corrosion-resistant piping and vessels for the chemical, petrochemical, and process industries. This would be done by combining Strubing made of a corrosion-resistant material such as tantalum and ordinary steel. Tantalum Strubing ribbon might, for example, be inserted in a pipe or tank and inflated to form an inner liner.

Company engineers believe that this technique could also be used for repairing sewers and water mains which develop leaks. Rather than having to rip up a street or other ground surface to remove and replace sections of pipe, strip tubing of some suitable material could be inserted and inflated to act as a protective "inner tube."

Big and Bigger

On the left in Figure 3 is one of the two new 80-ton pumps for the Chicago Metropolitan Sanitary District. The new pumps have a capacity of 180,000 gpm each and are driven by 3,000-hp steam turbines.

On the right is a 120,000-gpm unit which dates back to 1937 when four of these pumps were installed.

The total capacity of all six pumps is 840,000 gpm. The pumps were manufactured by the Worthington Corporation.

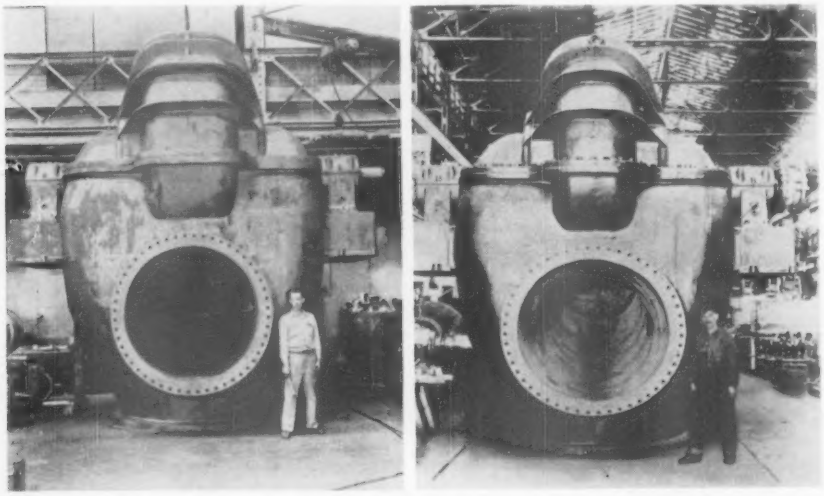

FIGURE 3.—On the left is a new 180,000-gpm pump for the Chicago Sanitary District; on the right is a 120,000-gpm unit which was installed in 1937.

Editorial

THE NEW NAME

The "Federation of Sewage and Industrial Wastes Associations" has changed its name to "Water Pollution Control Federation." This is now official. Of interest perhaps: Why the change? . . . Why this particular name?

Organizations, like ships, when launched are christened with a name. This is done amid jubilation, sober reflections, and optimistic predictions. An organization, unlike a ship, is not designed to carry people and things, but is itself to be carried by people as an instrument through which to improve people and things. A ship by its design and displacement has definite and prescribed limitations. An organization is not so handicapped. Its growth and influence are a function of its need and the vision, will, and competence of its membership.

An organization whose name relates to a broadening field of interest inevitably faces, in time, the name-change question—a change, not to satisfy an idle whim, but rather to be more in tune with the times.

The FSIWA was founded in 1928 as the Federation of Sewage Works Associations. In the view of the founders this name fit the needs and aspirations of the times. That the organization served the cause well is a clear matter of history. In 1950 the name was broadened to embrace industrial wastes. This modification was in recognition of the changing times.

In recent years we have witnessed an avalanche of change—with two major influences that will dominate wastewater policy. First, city sewage is no longer as we knew it in the twenties; it is now a complex municipal waste. Second, we are moving rapidly toward a pattern of gigantic metropolitan complexes.

Obviously, the Federation continues its basic interests in: wastewater collection and treatment; the status and quality of the technical manpower responsible for operation and maintenance; and the dissemination of technical information through its JOURNAL. On these primary objectives the name change certainly implies no policy shift. To sustain its leadership and influence, however, the Federation recognizes a broadening responsibility. The Federation also recognizes that the discriminating American public it serves has a mounting interest in the Nation's water resources and in the total need and total uses of these waters. The public expects a quality product from its treatment plant outfall—generally a higher quality product than it is willing to pay for. This introduces a public relations factor in the Federation's service formula—one to be given more attention in the future.

And so after long discussions and more than a year's considered attention, the name is changed. Obviously all will not applaud the new name. Some would have preferred no change at all; many placed major emphasis on the public relations factor as requiring a change. Some objected to the negative tone of the word "pollution"; others objected to the possible connotation in the word "control." But in our good American way, the majority rules and in this case a very large majority. Obviously the name itself is secondary—it is meaningful only to the extent that the organization develops its potential.

At any rate, we now have a "Water Pollution Control Federation." Let's move ahead.

MARK D. HOLLIS

Reviews and Abstracts*

The Dynamics of Volatile Organic Acids Formed During the Anaerobic Decomposition of Organic Compounds by Microorganisms in Methane Tanks. By V. I. Liubimov and Z. S. Kagan. *Mikrobiologiya* (USSR), **27**, 4, 476 (1958).

Propionic, butyric, isovaleric, acetic, and formic acids were formed during the laboratory maturation period (acid fermentation) in the mesophilic digestion of a mixture of primary and excess activated sludge. After the establishment of alkaline digestion, butyric, isovaleric, and propionic acids disappeared.

Samples taken from large-scale digestion tanks in the alkaline stage fed with activated sludge produced 0.95 me/l and with primary sludge 2.55 me/l of volatile acids. In addition to the above named acids, caproic acid was found, but butyric acid was present only infrequently in the digestion tanks.

In general, the picture of the ripening stage of the sludge in thermophilic digestion was similar to that of mesophilic digestion except that the composition and quantity of volatile acids in the alkaline stage of the thermophilic digestion resembled that observed in the mesophilic tank which had not yet ripened.

H. Heukelekian

The Effect of Oxidation-Reduction Conditions of the Medium on the Rate of Nitrate Reduction by Denitrifying Bacteria. By M. W. Federov and R. V. Sergava. *Mikrobiologiya* (USSR), **76**, 2, 151 (1957).

Denitrifying bacteria in the oxidation of organic matter use both molecular oxygen and nitrate oxygen as hydrogen acceptors. Under aerobic conditions they use both these acceptors simultaneously and in almost equal amounts. This can be accounted for by the fact that molecular oxygen diffuses slowly to the medium. Increasing the supply of molecular oxygen to the medium increases the utilization of molecular oxygen to 75 per cent, the balance being derived from nitrate. Nitrate reduction is not completely stopped, even under conditions of increased oxygen supply. Lowering the partial pressure of oxygen increases the rate of nitrate reduction reaching a maximum in anaerobic cultures.

H. Heukelekian

The Removal of TNT from Industrial Wastes. By V. Solin and K. Buriánek, Faculty of Technol. of Fuel and Water 2, Part 1, Inst. Chem. Technol., Prague. P. 237, English Summary (1958).

Experiments were carried out to learn the extent of removal of TNT from wastes by flocculation with ferric and aluminum compounds and by the adsorption on various materials.

It was proved that the flocculation of TNT wastes with ferric and aluminum compounds is of little effect. By adding 1 g/l ferric chloride or aluminum sulfate it is possible to reduce the quantity of TNT from 180 mg/l to 90 to 95 mg/l, or a removal of about 50 per cent.

For the adsorption of TNT wastes the dust of Winkler generators is most effective. By adding 0.5 g/l a reduction of TNT is attained of (a) from 180 to 5 mg/l, (b) from 120 to 3.5 mg/l, and (c) from 60 to 2 mg/l. By treating wastes with 2 g/l of Winkler dust all TNT was removed, and the water was clear.

Quite good results were obtained when the wastes were treated with generator and

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Water Pollution Control Federation, 4435 Wisconsin Ave., N.W., Washington 16, D. C.

furnace ashes from the burning of lignite. By treating wastes with 100 g/l of generator ash a reduction of TNT from 180 to 55 mg/l was attained; by treating it with 100 g/l of furnace ash, the quantity of TNT decreased to 70 mg/l. Although TNT is not completely removed, the ash effected a color-free water.

H. HEUKELEKIAN

BOOKS, REPORTS, PAMPHLETS

From Research to Classroom Laboratory. U. S. Dept. of Health, Education, and Welfare, Public Health Service, The Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio (1958).

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Proceedings of a seminar at which outstanding presentations were made on various aspects of streams.

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Report of Progress, 1957–1958. State of West Virginia, State Water Commission, Charleston, W. Va. 31 pp. (1958).

Annual Report of the Water Quality Division for 1958. Georgia Department of Public Health, Atlanta, Ga. 14 pp. (1959).

Statistical Summary of Sewage Works in the United States. BY JOHN R. THOMAN AND KENNETH H. JENKINS. U. S. Dept. of Health, Education, and Welfare, Public Health Service, Washington, D. C. Publication No. 609, 40 pp. Price $0.20 (1958).

Summary and data analysis on community sewage works in the U. S. based on 1957 Inventory.

Municipal Sewage Treatment Needs. BY JOHN R. THOMAN AND KENNETH H. JENKINS. U. S. Dept. of Health, Education, and Welfare, Public Health Service, Washington, D. C. Publication No. 619, 16 pp. Price $0.15 (1958).

Companion document to No. 609. Summary of sewage disposal requirements based on reported needs in 1957 Inventory.

Proceedings of 1958 Pennsylvania Clean Streams Conference. Pennsylvania State Chamber of Commerce, Harrisburg, Pa. (1958).

Accumulated papers given at the meeting, Apr. 18, 1958.

A Study of the Pollution and Natural Purification of the Ohio River. III. Factors Concerned in the Phenomena of Oxidation and Reaeration. BY H. W. STREETER AND EARLE B. PHELPS. U. S. Public Health Service, Bulletin No. 146 (Feb. 1925); reprinted by U. S. Dept. of Health, Education, and Welfare, Public Health Service, Washington, D. C. 75 pp. (1958).

A reprinting of the classic Ohio River study.

Interstate Sanitation Commission Report 1958. Interstate Sanitation Commission, New York (1959).

Baltimore County Department of Public Works Progress and Accomplishments 1951–1957. Baltimore County Department of Public Works, Towson, Md. 174 pp. (1958).

An illustrated seven-year progress report covering a period of expanded population and attendant problems.

Air-Stream Pollution Control. Sponsored by the United States Public Health Service, New Jersey Department of

Health, Rutgers University, and American Cyanamid Company. Published by American Cyanamid Company, New York. 64 pp. (1958).

Proceedings of a seminar held June 4, 1958, at Bound Brook, N. J.

Water Inventory of the Cuyahoga and Chagrin River Basins Ohio. State of Ohio, Department of Natural Resources, Division of Water, Columbus, Ohio. Volume 1. 90 pp. Price $2.75 (1959).

Basic report which includes 31 maps, charts, and other illustrations.

Water Inventory of the Cuyahoga and Chagrin River Basins Ohio. State of Ohio, Department of Natural Resources, Division of Water, Columbus, Ohio. Volume 2 (map atlas, 15 × 20 in.) 32 pp. Price $3.25 (1959).

Contains 26 color maps or charts, and data, of water recreation areas, major land use areas, population, principal water withdrawals, quality of water, watershed areas, availability of surface water, availability of ground water, possible reservoir sites, and soil areas.

Lake Superior Study—1956. By Orlando R. Ruschmeyer, Theodore A. Olson, Herbert M. Bosch, A. C. Redfield, and T. O. Odlang. School of Public Health, University of Minnesota, Minneapolis, Minn. 79 pp. (June 1957).

Illustrated and tabulated report of limnological studies of Lake Superior.

Treatment of Overflows from Combined Sewerage Systems by Use of Storm Water Storage and Chlorination. New Hampshire Water Pollution Commission, Concord, N. H., Staff Report No. 40. 12 pp. and Appendix (1959).

Procedure and computations for determining the feasibility of storing and chlorinating storm-water overflows are given. In making the exploratory study, two land areas are used. Prevention of contamination of bathing water motivated the study.

Water Movements and Temperatures of Western Lake Superior. By Orlando R. Ruschmeyer, Theodore A. Olson, Herbert M. Bosch, and Theron O. Odlang. 86 pp. (Nov. 1958).

Second in the series of limnological studies of Lake Superior.

Honeywell Index of Literature. Bulletin G2-1a, Minneapolis-Honeywell Regulator Company, Industrial Division, Philadelphia, Pa. 24 pp. (1959).

A list of product catalogs, industry and systems bulletins, technical bulletins, specifications, instrumentations data sheets, subject index to "Instrumentation," and educational aids.

Sewage Treatment Works Contract Awards 1952–1957. By William H. Abbott, and Lewis C. Hudson, Jr. U. S. Department of Health, Education, and Welfare, Public Health Service, Washington, D. C. 93 pp. Price 50 cents (1958).

Report of the Joint Program of Studies on the Decontamination of Radioactive Wastes. By Health Physics Division, Oak Ridge National Laboratory, and Robert A. Taft Sanitary Engineering Center, Public Health Service. Office of Technical Services, U. S. Department of Commerce, Washington, D. C. ORNL-2557 Radioactive Waste TID-4500 (14th ed.) 62 pp. Price $1.00 (1959).

A joint report on the effectiveness of water treatment processes in the removal of radioactive waste materials.

Proceedings—National Conference on Air Pollution. U. S. Department of Health, Education, and Welfare, Public Health Service, Washington, D. C. Public Health Service Publication No. 654, 526 pp. Price $1.75 (1959).

Complete proceedings of an air pollution conference held in Washington, November 18–20, 1958.

Report to the People of Pennsylvania—Your Clean Streams Program. Pennsylvania Department of Health, Sanitary Water Board—Division of Sanitary Engineering, Harrisburg, Pa. (1959).

A public relations brochure in two colors.

Municipal Water Facilities Communities of 25,000 Population and Over, Continental United States and Territorial Possessions as of January 1, 1958. U. S. Department of Health, Education, and Welfare, Public Health Service, Washington, D. C. Public Health Service Publication No. 661, 83 pp. (1959).

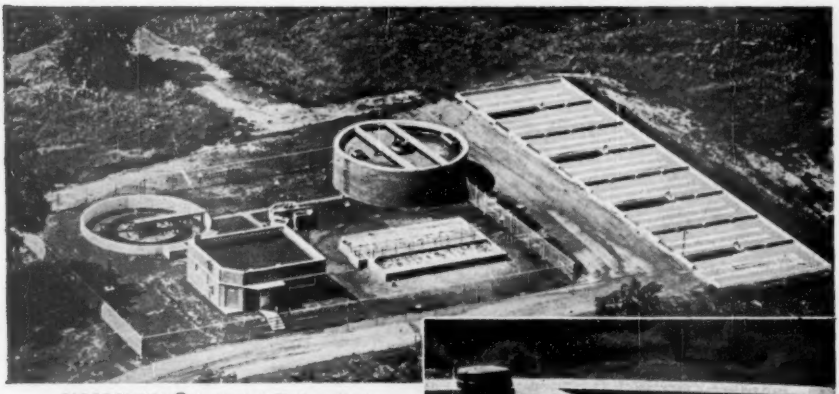

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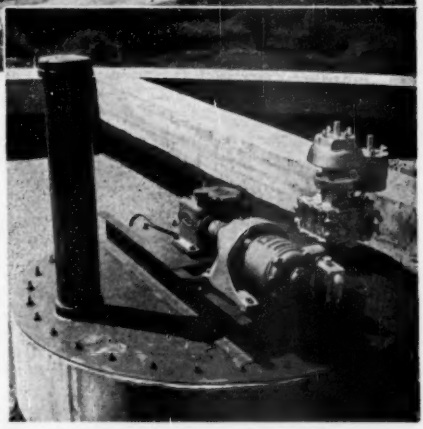
FIG. No. 5800C



"VAREC" Fig. No. 5800C
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2. Much more flow per minute than same size competitive equipment, due to less capillarity and friction in the Flame Arrester passageways; streamlining and expanding passageways of Pressure Relief and Vacuum Breaker Valve.

3. Easy to clean. Just loosen frame holding Flame Arrester plates together — plates separate to permit easy cleaning with distillate, chemical solution or wire brush.

4. All aluminum construction makes "VAREC" Pressure Relief and Vacuum Breaker Valve corrosion resistant. Lighter weight facilitates installation.

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Proceedings of Member Associations

OHIO SEWAGE AND INDUSTRIAL WASTES TREATMENT CONFERENCE

The 33rd Annual Meeting of the Ohio Sewage and Industrial Wastes Treatment Conference was held at the Netherland Hilton Hotel, Cincinnati, Ohio, June 17–19, 1959.

Registration totaled 297 including 35 ladies.

The Manufacturers' Forum on June 17, featured papers on centrifuges with particular reference to applications in the sewage treatment field. The general afternoon session was opened by an address of welcome followed by a paper on the "Development of the Mill Creek Works," by Alvin Mock of Havens and Emerson. FSIWA Executive Secretary Ralph Fuhrman conveyed Federation greetings. The business session and sectional group reports concluded the day's organized activities.

The morning program of June 18 was divided into concurrent sessions. The sewage session featured panel discussions on "Plant Controls" and "Sewer Rentals and Rate Studies." The industrial wastes session heard papers on "Water Pollution as Related to the Problem of Water Resources," "A Method of Handling of Distillery Waste Materials," "Indiana Experiences in Controlling Acid Mine Drainage," and "Dewatering of Paper Mill Waste Sludges."

The dedication ceremonies of the Mill Creek Sewage Treatment Works

(*Continued on page 28a*)

SNOW GATES
for
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All types of cast iron gates manufactured in either square or circular opening in sizes up to and including 72 inches.

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SEWAGE AND INDUSTRIAL WASTES

INDEX

Volumes 21-30, 1949-1958

The Ten-Year Index to SEWAGE AND INDUSTRIAL WASTES covering the period of 1949–1958 is now available. The 168-page volume is offered in a handsome maroon buckram binding at $4.00 and in an attractive heavy paper cover at $3.00.

The new Ten-Year Index is a companion to the previous Twenty-Year Index to the first 20 volumes of SEWAGE WORKS JOURNAL for 1928–1948, copies of which are still available from the Federation office.

Separate listings by author, subject, and geographical categories, along with full cross-referencing make this a complete and easy-to-use reference volume.

Send orders to the Federation office. When remittance accompanies order, postage is prepaid. If an invoice is necessary, postage will be added. Checks may be made payable to WPCF.

WATER POLLUTION CONTROL FEDERATION

4435 Wisconsin Avenue **Washington 16, D.C.**

and the inspection trip through the plant took place on the afternoon of June 18. This ceremony was preceded by a Chamber of Commerce luncheon at which Arthur Flemming, Secretary of Health, Education & Welfare, was the guest speaker.

The conference was concluded with the dual sessions on June 19. The sewage session presented a panel discussion on "Does Your Digester Control You," followed by papers on "Studies of a Peripheral-Feed Circular Basin" and "Automatic Proportionate Samplers for Installation in Manholes." The industrial wastes session heard papers on "Odor Thresholds of Mixed Organic Chemicals," "Wastes from the Processing of Corn Chips," "Do Analytical Methods Assess the Effects of Discharges into Streams," and "Household Detergents in Water and Sewage Treatment."

Following the Banquet the Dean Stewart Award was presented to Max B. Phillips *in absentia*, the J. W. Ellms Award was presented to A. H. Niles, and the newly created F. M. Waring Award was presented to Robert N. Simonsen.

Officers elected for 1959–60 were:

Chairman: E. W. Petrich, Urbana.

1st Vice-Chairman: A. D. Caster, Cincinnati.

2nd Vice-Chairman: R. N. Simonsen, Cleveland.

Secretary-Treasurer: E. B. Ransom, Columbus.

W. E. Conrad
Secretary-Treasurer

IOWA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 41st Annual Meeting of the Iowa Sewage and Industrial Wastes Asociation was held at the Roosevelt

(*Continued on page 31a*)

AMERICAN-MARIETTA

plants serve more than 85 percent of the U.S., assuring you of quick technical help when needed and fast delivery of such precast concrete products as:

- ROUND PIPE: SEWERS, CULVERTS AND WATER PIPE
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Ind., Lafayette, P.O. Box 537
Iowa, Sibley, P.O. Box 307
Mich., Grand Rapids 9, Box R-20
N.M., Albuquerque, P.O. Box 1629
N.Y., New York 7, 50 Church St.
N.Y., Syracuse 6, P.O. Box 85, Eastwood Sta.
N.C., Charlotte 1, P.O. Box 10004
Ohio, Columbus 15, 555 Furnace St.
Ohio, Marietta, P.O. Box 356
Okla., Oklahoma City, P.O. Box 1024
Ontario, Toronto 13, P.O. Box 160, Station H
Penn., Norristown, P.O. Box 230
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Tenn., Memphis 8, P.O. Box 6833, Hollywd. Sta.
Vermont, Windsor, P.O. Box 48
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1. LO-HED PIPE carries a greater flow than its round equivalent—in a shallower trench with adequate depth of cover.

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A-M's elliptical concrete pipe was chosen for this combination sewer project because of its increased self-cleansing velocities at periods of dry-weather flow—and used in three ways on this single job . . . as Lo-Hed, Hi-Hed and Inner Circles Pipe. The two mile line, engineered by Consoer Townsend & Associates, Chicago, runs from the Teletype Corporation in Niles, Illinois, to the north branch of the Chicago River.

American-Marietta's reinforced elliptical, as well as round, pipe is available in a full range of sizes with pretested strengths to meet various specifications—can be delivered in quantity when and where needed from any of A-M's many plants located from coast to coast.

Our technical staff will be pleased to assist you with your pipe problems

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WATER POLLUTION CONTROL PRODUCT GUIDE

This list of products and services is offered as an information aid. The list was derived by solicitation from those firms listed. The JOURNAL will make every effort to keep this list current with the help of members and advertisers. All Associate Members and all advertisers for the past calendar year are included. Many of the services and products are advertised in this issue. See page 47a for an alphabetical listing.

Aerators (*also see* Diffusers, Air)
Alpha Ltd. (Switzerland)
American Well Works
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Infilco Inc.
Link-Belt Co.
Pacific Flush Tank Co.
Penberthy Mfg. Co., Div. of Buffalo-Eclipse Corp.
Permutit Co., Div. of Pfaudler-Permutit Inc.
Smith & Loveless, Inc.
Walker Process Equipment Inc.
Wemco Div., Western Machinery Co.
Yeomans Brothers Co.
Zimmer & Francescon

Agitators
Link-Belt Co.

Air Cleaning Equipment
Westinghouse Electric Corp.

Air Compressors (*also see* Blowers, Compressors, and Fans)
Chicago Pump Co.
Fairbanks, Morse & Co.
Komline-Sanderson Engr. Corp.
Worthington Corp.
Yeomans Brothers Co.

Air Diffusers (*see* Diffusers, Air)

Asbestos Cement Pipe Products
Filtration Equipment Corp.
Industrial Materials Co.
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Ash Handling Equipment
Link-Belt Co.

Automobiles and Trucks
Vulcan Materials Co.

Bearings
Link-Belt Co.

Bins, Storage (*see* Tanks)

Biologists (*see* Directory of Engineers)

Blowers (*also see* Air Compressors, Compressors, and Fans)
Chicago Pump Co.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Boilers
Combustion Engineering, Inc.

Building Maintenance Equipment and Supplies
Homestead Valve Mfg. Co.

Cast Iron Pipe Products
American Cast Iron Pipe Co.
Cast Iron Pipe Research Assn.
Industrial Materials Co.
U. S. Pipe & Foundry Co.
R. D. Wood Co.

Cement (*see* Concrete)

Centrifuging Equipment
Bird Machine Co.

Chains
Chain Belt Co.
Link-Belt Co.
Webster Mfg., Inc.

Chemical Feed Equipment
Builders-Providence Div., B-I-F Industries
Eimco Corp.
Fischer & Porter Co.
Graver Water Conditioning Co.
Infilco Inc.
Jeffrey Mfg. Co.
Komline-Sanderson Engr. Corp.
Link-Belt Co.
Omega Div., B-I-F Industries
Permutit Co., Div. of Pfaudler-Permutit Inc.
Proportioneers Div., B-I-F Industries
Wallace & Tiernan Inc.

Chemicals
Cloroben Chemical Corp.
Dow Chemical Co.
General Chemical Div., Allied Chemical Corp.
Tennessee Corp.
Vulcan Materials Co.

Chemists (*see* Directory of Engineers)

Chlorination Equipment
Builders-Providence Div., B-I-F Industries
Everson Mfg. Co.
Fischer & Porter Co.
Graver Water Conditioning Co.
Wallace & Tiernan Inc.
Zimmer & Francescon

Clarifier Equipment (*also see* Sedimentation Equipment)
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Komline-Sanderson Engr. Corp.
Lakeside Engineering Corp.
Link-Belt Co.
Permutit Co., Div. of Pfaudler-Permutit Co.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Clay Pipe Products
Industrial Materials Co.
National Clay Pipe Mfrs., Inc.
Wedge-Lock Clay Pipe Mfrs., Inc.

Coatings and Linings (Pipe and Tank)
Amercoat Corp.
Centriline Corp.
Inertol Co., Inc.
Koppers Co., Inc.
National Water Main Cleaning Co.
Perry-Austen Mfg. Co.
Pittsburgh Coke & Chemical Co.
Stebbins Engr. & Mfg. Co.
Vulcan Materials Co.

Comminutors (*also see* Shredders and Grinders)
Alpha Ltd. (Switzerland)
American Well Works
Chicago Pump Co.
Dorr-Oliver Inc.
Gruendler Crusher & Pulverizer Co.
Infilco Inc.
Jeffrey Mfg. Co.
Smith & Loveless, Inc.
Walker Process Equipment Inc
Worthington Corp.

Compressors
Chicago Pump Co.
Fairbanks, Morse & Co.
Komline-Sanderson Engr. Corp.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Worthington Corp.
Yeomans Brothers Co.

Computers
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.

Concentrators (*see* Sludge Concentrators)

Concrete
Portland Cement Assn.
Vulcan Materials Co.

Concrete Pipe Products
American Concrete Pressure Pipe Assn.
American-Marietta Co.
Gray Concrete Pipe Co., Inc.
Industrial Materials Co.
Lock Joint Pipe Co.
Portland Cement Assn.
Price Bros. Co.
Vulcan Materials Co.

Construction Equipment
Chain Belt Co.
Eimco Corp.
Worthington Corp.

Controls (*also see* Instruments, Recording and Control)
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Builders-Providence Div., B-I-F Industries

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★ Sewer and Pipe Cleaning Equipment

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★ Braces and Guides

★ Buckets, Root Cutters, Drag Tools

Save the cost of experimenting. Consult Stewart for any problem in the specialized field of pipe cleaning.

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Hotel, Cedar Rapids, Iowa, June 17–19, 1959. Total registration for the technical sessions was 165, and the ladies registration was 29.

The technical sessions covered all phases of treatment processes as well as allied topics. The first topic discussed was the design, construction, and maintenance of sewers. This was followed by papers on public relations, wet method of sludge disposal, oxidation ponds, and preaeration of sewage. During the second day's program there were discussions on: new developments in sewage treatment plant design and operation, pretreatment and irrigation of packing house wastes, and first aid and safety. A full afternoon was devoted to a tour of the Cedar Rapids sewage treatment plant.

At the Association Luncheon, FSIWA President W. D. Hatfield spoke of the past, present, and future of the Federation. At the Annual Banquet the Bedell Award for outstanding contributions to the Association was presented to H. S. Smith, Sanitary Engineer, Stanley Engineering Co., Muscatine. The Hatfield Award for outstanding plant operation was presented to M. F. Neuzil, Superintendent, Iowa City sewage treatment plant. The Iowa Association's Achievement Award went jointly to Verl Garwood, Superintendent, Grinnell sewage treatment plant, and the city of Grinnell.

The following officers were elected to serve for the year 1959–60:

President: D. D. Douglas, Fort Dodge.
Vice-President: M. P. Powell, Iowa City.
Secretary: L. F. Skorczeski, Marshalltown.
Treasurer: Harry E. Boren, Marion.
FSIWA Director: H. S. Smith, Muscatine.

L. F. SKORCZESKI
Secretary

(*Continued on page 33a*)

Burgess-Manning Co., Penn Instruments Div.
Chicago Pump Co.
Fischer & Porter Co.
Foxboro Co.
General Electric Co.
Homestead Valve & Meter Co.
Infilco Inc.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Permutit Co., Div. of Pfaudler-Permutit Co. Inc.
Rockwell Mfg. Co.
Wallace & Tiernan Inc.
Westinghouse Electric Corp.
Worthington Corp.

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Chain Belt Co.
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Jeffrey Mfg. Co.
Link-Belt Co.
Stuart Corp.
Webster Mfg., Inc.

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Chicago Pump Co.
Inertol Co., Inc.
Johns-Manville Sales Corp.
Koppers Co., Inc.
Perry-Austen Mfg. Co.
Stebbins Engr. & Mfg. Co.
Wallace & Tiernan Inc.

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Carborundum Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Lakeside Engineering Corp.
Link-Belt Co.
Pacific Flush Tank Co.
Penberthy Mfg. Co., Div. of Buffalo-Eclipse Corp.
Walker Process Equipment Inc.
Wemco Div., Western Machinery Co.
Zimmer & Francescon

Diffusers, Gas (*also see* Aerators)
American Well Works
Carborundum Co.
Chicago Pump Co.
Eimco Corp.
Infilco Inc.
Walker Process Equipment Inc.
Yeomans Brothers Co.

Digestion Tank Equipment
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Gorman-Rupp Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Lakeside Engineering Corp.
Link-Belt Co.
Pacific Flush Tank Co.
Smith & Loveless, Inc.
Vapor Recovery Systems Co.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Distributors, Rotary
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Lakeside Engineering Corp.
Link-Belt Co.
Pacific Flush Tank Co.
Smith & Loveless, Inc.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Dryers
Alpha Ltd. (Switzerland)
Combustion Engineering, Inc.
Eimco Corp.
Hardinge Co., Inc.
Komline-Sanderson Engr. Corp.
Link-Belt Co.
Nichols Engr. & Research Corp.
Stuart Corp.

Ejectors
Komline-Sanderson Engr. Corp.
Smith & Loveless, Inc.
Tex-Vit Supply Co.
Yeomans Brothers Co.

Engineers (*see* Directory of Engineers)

Engines (Sludge Gas and Petroleum Fuels)
Climax Engine Mfg. Co.
Fairbanks, Morse & Co.
Waukesha Motor Co.
Worthington Corp.

Fans (*also see* Air Compressors, Blowers, and Compressors)
Chicago Pump Co.
Lakeside Engineering Corp.
Westinghouse Electric Corp.

Filter Equipment, Trickling
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Dorr-Oliver Inc.
Dow Chemical Co.
Eimco Corp.
Filtration Equipment Corp.
Industrial Materials Co.
Infilco Inc.
Keasbey & Mattison Co.
Komline-Sanderson Engr. Corp.
Lakeside Engineering Corp.
Nichols Engr. & Research Corp.
Pacific Flush Tank Co.
Smith & Loveless, Inc.
Trickling Filter Floor Inst.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Filter Materials
Carborundum Co.
Filtration Equipment Corp.
Graver Water Conditioning Co.
Industrial Materials Co.
Johns-Manville Sales Corp.
Vulcan Materials Co.

Filters, Diatomaceous Earth
Graver Water Conditioning Co.
Yeomans Brothers Co.

Filters, Vacuum (*also see* Vacuum Filters)
Bird Machine Co.
Dorr-Oliver Inc.
Eimco Corp.
Proportioneers Div., B-I-F Industries

Flocculating Equipment
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Lakeside Engineering Corp.
Link-Belt Co.
Stuart Corp.
Walker Process Equipment Inc.
Webster Mfg., Inc.
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Flotation Equipment
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Komline-Sanderson Engr. Corp.
Yeomans Brothers Co.

Flow Measurement
Bailey Meter Co.
Burgess-Manning Co., Penn Instruments Div.
Filtration Equipment Corp.

Gas Control Equipment
Alpha Ltd. (Switzerland)
Burgess-Manning Co., Penn Instruments Div.
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Foxboro Co.
Homestead Valve Mfg. Co.
Pacific Flush Tank Co.
Rockwell Mfg. Co.
Vapor Recovery Systems Co.
Walker Process Equipment Inc.
Zimmer & Francescon

Gas Diffusers (*see* Diffusers, Gas)

Gas Holders, Boilers, and Appurtenances
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Johns-Manville Sales Corp.
Pittsburgh-Des Moines Steel Co.
Walker Process Equipment Inc.

Gaskets
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Gates
Armco Drainage & Metal Products, Inc.
Filtration Equipment Corp.
Industrial Materials Co.
Snow Gates & Valves, Inc.
Webster Mfg., Inc.

Generators
Climax Engine Mfg. Co.
Fairbanks, Morse & Co.
General Electric Co.
Westinghouse Electric Corp.
Worthington Corp.

Grease Control Materials
Cloroben Chemical Corp.

Grinders (*also see* Shredders and Grinders)
Alpha Ltd. (Switzerland)
American Well Works
Chain Belt Co.
Dorr-Oliver Inc.
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.
Yeomans Brothers Co.

Grit Collection and Conditioning Equipment
Alpha Ltd. (Switzerland)
American Well Works
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Jeffrey Mfg. Co.
Link-Belt Co.
Stuart Corp.
Walker Process Equipment Inc.
Webster Mfg., Inc.
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ROCKY MOUNTAIN SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The Rocky Mountain's 23rd Annual meeting is now history. This year, as in the past, the meeting was held in conjunction with the local section of the AWWA. In all, approximately 140 registered for the convention. About 70 were members of our organization.

This registration was quite respectable considering that the location of the convention was over 500 miles from Denver and 1,000 miles from some members' homes in New Mexico. Of course, the beautiful setting of Jackson Lake Lodge, Wyo., will have to be given credit.

Among the papers of interest to those connected with water pollution control were:

"Why Sewage Treatment?" by Ernest Martinez, Water and Sewer Superintendent, Taos, N. Mex.

"Uranium Wastes," by Bill Gahr, Sanitary Engineer, Colorado State Health Department.

"The Sportsman and the Polluted Stream," by Robert Kimball, Executive Director, Colorado Fish and Game Commission.

"The Detergent Problem," by Ralph House, California Research Corp., Richmond, Calif.

"Federal Aid Programs," by Kaarlo Nasi, U. S. Public Health Service.

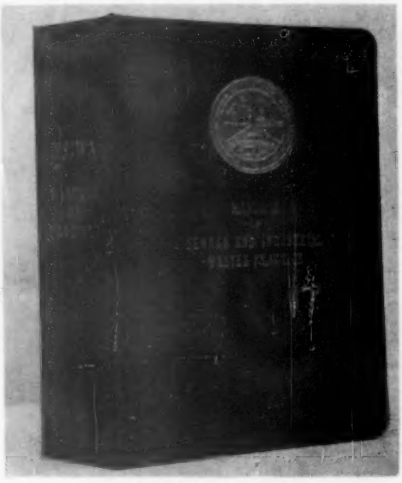
"New Methods of Industrial Waste Treatment," by K. S. Watson, Past-President, FSIWA.

"Operator Certification," by Howard Lewis, Superintendent, Coor's Corp.

"Application of Variable Speed Pumping," by Tom G. Gressett, Mechanical Engineer, Denver, Colo.

"Non-Vitrified Sewer Tile," by Harold Peterson, Brikcrete Mfg. Co.

(Continued on page 35a).



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"Valves for Sewage Works," by Everett M. Jones, Rockwell Mfg. Co.

"New Equipment Available for Sewage Treatment,"—Panel Discussion.

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The Annual Conference was held at Bournemouth, June 22–26, 1959.

Among the papers presented were:

"A Review of Recent Activated Sludge Research at Manchester," by J. McNicholas and H. B. Trench, Manchester Corporation Rivers Department.

"A Contribution to the Development in the Activated Sludge Process," by A. Pasveer.

"Continental Sewage Treatment Plants," by C. B. Townsend.

"Disposal of Wastes from Communities of Diverse Size and Function," by G. Lloyd Ackers, Ministry of Works.

"Charges for Treatment of Trade Effluent," by J. Griffiths and A. A. Kirkbright, Middlesex County Council Main Drainage Department.

"Some Uses of Radioisotopes in the Study of Sewage Treatment Processes," by G. E. Eden.

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Metal Packing—Bulletin AD-166 deals with metal packings for pumps, engines, and compressors. The 24-page booklet contains comprehensive data for correct selection, application, and installation.—Garlock Packing Company, 438 Main St., Palmyra, N. Y.

Portable Light Plant—A new type of semi-brushless light plant (Figure 1) which has no commutator and utilizes vertical-type slip rings is available. The generator has been designed in such a manner that all normal maintenance can be made at the open end of the unit. The model shown in Figure 1 is a 1,700-w plant.—Katolight Corporation, Mankato, Minn.

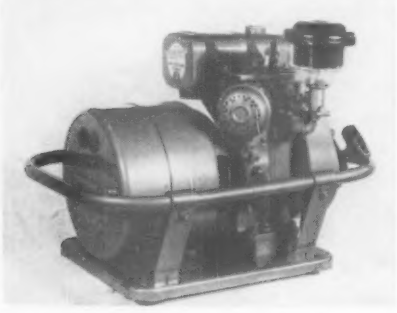

FIGURE 1.—Portable light plant.

In-Stream Flow Transmitter—A new, in-stream, flow transmitter eliminates the need for stilling wells and expensive maintenance. The transmitter utilizes a float arrangement with a 6-in. expanded polystyrene float riding directly in the channel.—Write for Bulletin 230.20A-3, B-I-F Industries, Inc., 345 Harris Ave., Providence 1, R. I.

Slurry Pump—A controlled volume pump (Figure 2) utilizing the Oliver diaphragm slurry pump principles is now being produced by the Milton Roy Company, 1300 E. Mermaid Lane, Philadephia 18, Pa. Capacities go to 180 gph, and it is claimed that slurries containing up to 60 per cent solids can be handled.

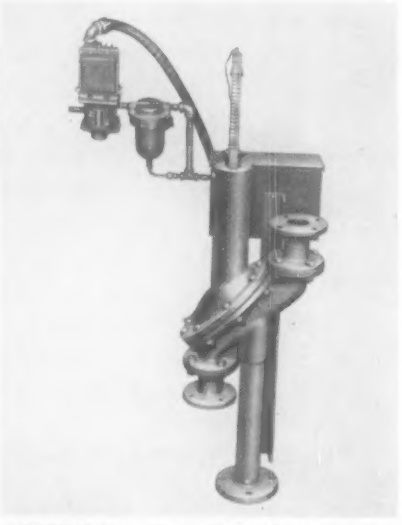

FIGURE 2.—Controlled volume pump.

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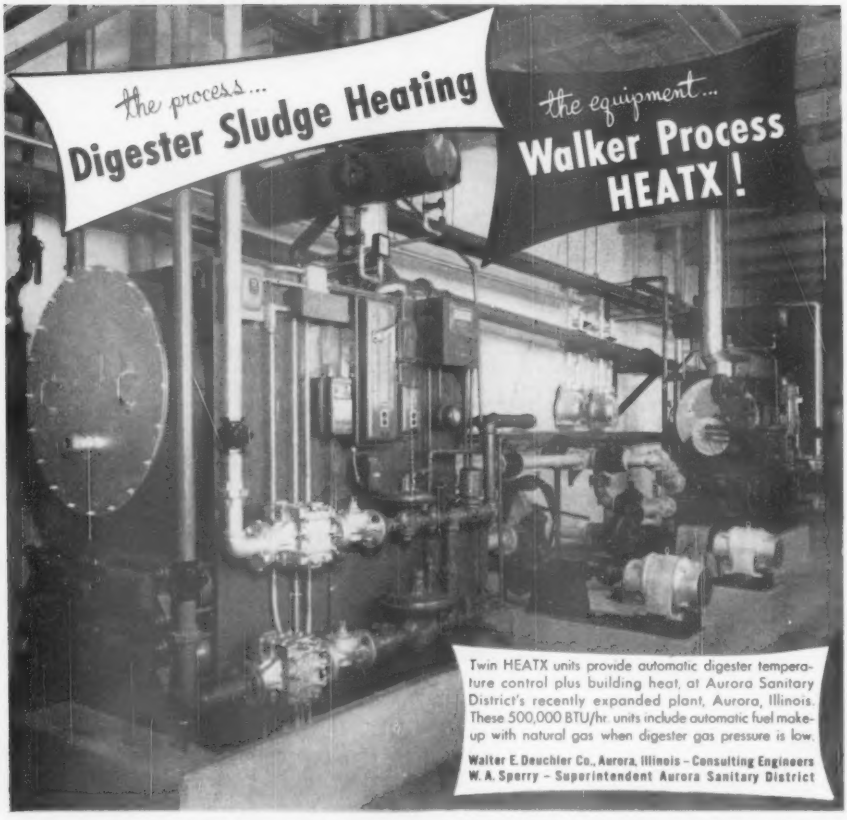

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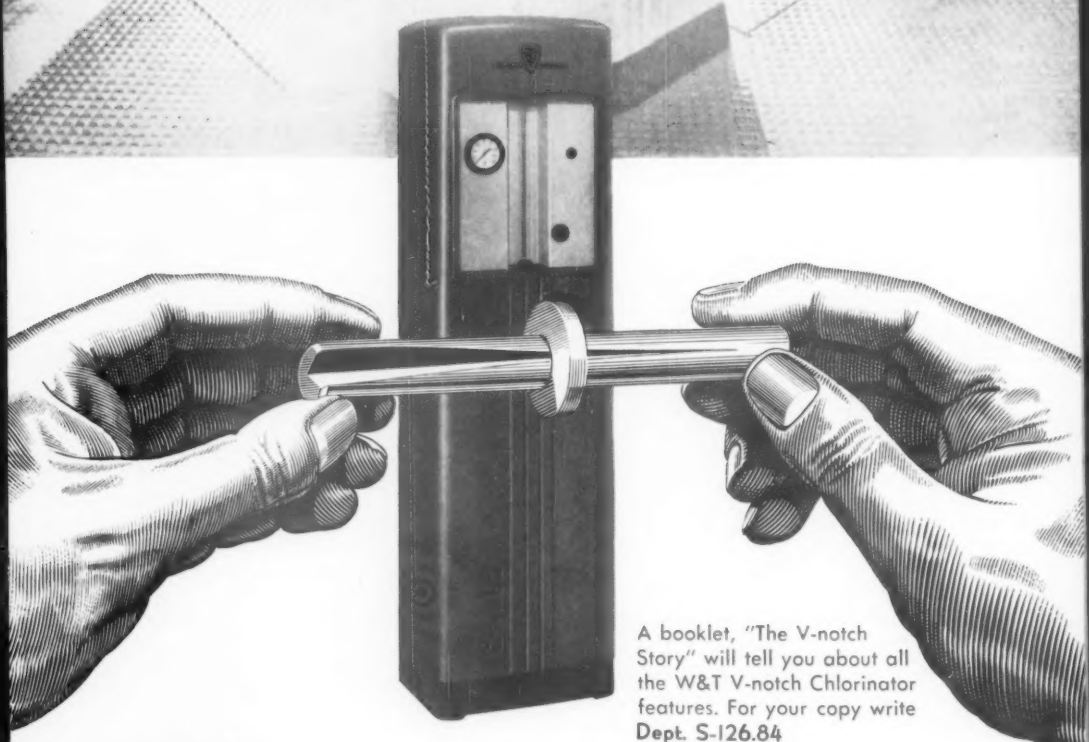

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